Technical Report 1057

Learning in a Synthetic Environment: The Effect of Visual Display, Presence, and Simulator Sickness

David M. Johnson
U.S. Army Research Institute

February 1997

United States Army Research Institute for the Behavioral and Social Sciences

U.S. ARMY RESEARCH INSTITUTE
FOR THE BEHAVIORAL AND SOCIAL SCIENCES

A Field Operating Agency Under the Jurisdiction of the Deputy Chief of Staff for Personnel

EDGAR M. JOHNSON
Director

Technical review by

David S. Hamby, ARI
Kevin Hathaway, DOTDS
John E. Stewart, ARI
Dennis C. Wightman, ARI

REPORT DOCUMENTATION PAGE

1. REPORT DATE 1997, February	2. REPORT TYPE Final	3. DATES COVERED (from. . . to) April 1995-January 1996
4. TITLE AND SUBTITLE Learning in a Synthetic Environment: The Effect of Visual Display, Presence, and Simulator Sickness		5a. CONTRACT OR GRANT NUMBER
		5b. PROGRAM ELEMENT NUMBER 0602785A
6. AUTHOR(S) David M. Johnson (ARI)		5c. PROJECT NUMBER A791
		5d. TASK NUMBER 2211
		5e. WORK UNIT NUMBER H01
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Institute for the Behavioral and Social Sciences ATTN: PERI-IR 5001 Eisenhower Avenue Alexandria, VA 22333-5600		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Institute for the Behavioral and Social Sciences 5001 Eisenhower Avenue Alexandria, VA 22333-5600		10. MONITOR ACRONYM ARI
		11. MONITOR REPORT NUMBER Technical Report 1057

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT *(Maximum 200 words)*:

Soldiers explored a synthetic representation of an Army heliport under three visual display conditions: (1) wide field of view (FOV) helmet-mounted display, (2) narrow FOV helmet-mounted display, and (3) stationary, wide-screen display. Pretest and posttest measures of spatial knowledge were recorded. Measures of presence in the virtual environment were recorded. Measures of simulator sickness were administered upon exit from the virtual environment and 24 hours later.

Overall, soldiers acquired a significant amount of spatial knowledge from the synthetic representation. When transferred to the actual Army heliport, soldiers were able to navigate around the location with near-zero errors. There was no effect of visual display on any measures of spatial knowledge. Also, there was no effect of visual display on reported presence or simulator sickness. Simulator sickness was significantly reduced after 24 hours away from the virtual environment. Presence did not correlate with spatial knowledge. Simulator sickness correlated negatively with spatial knowledge. Presence and simulator sickness were negatively correlated.

15. SUBJECT TERMS

Virtual environments	Spatial learning	Virtual reality
Simulator sickness	Synthetic environments	Simulator research

SECURITY CLASSIFICATION OF			19. LIMITATION OF ABSTRACT	20. NUMBER OF PAGES	21. RESPONSIBLE PERSON (Name and Telephone Number)
16. REPORT Unclassified	17. ABSTRACT Unclassified	18. THIS PAGE Unclassified	Unlimited	79	Charles A. Gainer (334) 255-2834

Technical Report 1057

Learning in a Synthetic Environment: The Effect of Visual Display, Presence, and Simulator Sickness

David M. Johnson
U.S. Army Research Institute

Rotary-Wing Aviation Research Unit
Charles A. Gainer, Chief

U.S. Army Research Institute for the Behavioral and Social Sciences
5001 Eisenhower Avenue, Alexandria, Virginia 22333-5600

Office, Deputy Chief of Staff for Personnel
Department of the Army

February 1997

Army Project Number
20262785A791

Education and Training Technology

FOREWORD

The research discussed in this report was performed by the Simulation Team of the U.S. Army Research Institute for the Behavioral and Social Sciences' (ARI) Rotary-Wing Aviation Research Unit at Fort Rucker, Alabama. ARI is committed to enhancing aviation training in the Army. A cornerstone of this commitment is the Simulator Training Research Advanced Testbed for Aviation (STRATA). STRATA research objectives are to (1) determine the minimal levels of simulator fidelity required to meet specific task training objectives, (2) define effective training strategies for flight simulator technology so as to attain and sustain combat readiness for individual tasks and collective training, and (3) delineate effective ways to train for new operational equipment and tactics based on realistic simulations of battlefield environments. Future efforts will focus on strategies for unit level networked training systems using the recently developed, multiplayer, STRATA network.

STRATA has a modular component design so that it can be reconfigured quickly and extensively to emulate a range of training devices--from procedures trainers to full mission simulators. Among STRATA's features are (1) an automated interactive tactical environment, (2) a head- and eye-tracked helmet-mounted display providing for immersion in a computer-generated environment, and (3) the capability to link to Distributed Interactive Simulations (DIS) as a functional node. A demonstration of this capability was performed in March 1994 when STRATA was linked to five Apache simulators residing in Mesa, Arizona using DIS protocol 2.03.

In recent research, STRATA's flexibility has been exploited as a prototype synthetic environments training system. Recently, synthetic environment technologies have been proposed as a cost effective means to provide training in such critical military tasks as premission planning and mission rehearsal. Issues for behavioral research include the transfer of training from these virtual environments to the real world; the visual interface requirements for terrain familiarization in these environments; the importance of a sense of presence within the computer-generated environment; and any possible negative side effects resulting from training soldiers in synthetic environments. The present research examined these issues.

Zita M. Simutis

ZITA M. SIMUTIS
Technical Director

Edgar M. Johnson

EDGAR M. JOHNSON
Director

ACKNOWLEDGMENTS

The author would like to express his sincere gratitude to the following employees of the Army Research Institute for the Behavioral and Social Sciences (ARI), Anacapa Sciences Incorporated (ASI), and CAE Electronics Limited (CAE). The contributions of their time, effort, expertise, and creativity made possible the timely execution of this technically demanding research effort.

ARI-- MAJ Keenan J. Kline, 2LT Anthony J. Encarnacao, and Remona S. Wright

ASI-- Laura F. Dunleavy

CAE-- Nick Donker, Rolf Beutler, Yves Provencher, Marco Verardo, Dale Weiler, Ohannes Younanian, and Fred Zalzal

LEARNING IN A SYNTHETIC ENVIRONMENT: THE EFFECT OF VISUAL DISPLAY, PRESENCE, AND SIMULATOR SICKNESS

EXECUTIVE SUMMARY

Research Requirement:

To determine if synthetic environments technology can be used to familiarize soldiers with a geospecific location that they have never previously visited. Can important spatial knowledge be acquired via this medium? Will this knowledge transfer to the actual, physical location? What is the relationship between the experience of presence in the synthetic environment and performance of the spatial learning task? What is the relationship between simulator sickness and performance of the spatial learning task? Will performance on the learning task, presence, and simulator sickness be affected by differences in visual display technologies used in the synthetic environment?

Procedure:

The experiment employed a three-group, pretest-posttest design. The domain modeled in the synthetic environment was the Hanchey Army Heliport (HAH) located at Fort Rucker. No participants had visited the HAH prior to the experiment. Independent groups of soldiers explored this synthetic representation under three different visual display conditions: (1) wide field of view (FOV) helmet-mounted display, (2) narrow FOV helmet-mounted display, and (3) conventional, stationary, wide-screen display. Sixty minutes of exploration were performed by all 30 soldiers. All groups were tested both before and after exploration of the synthetic environment on their knowledge of the HAH. A questionnaire was administered after exploration to record ratings of presence experienced in the virtual environment. The Simulator Sickness Questionnaire was administered both immediately after exit from the synthetic environment and 24 hours later. This questionnaire recorded ratings of discomfort experienced as a result of exposure to the virtual environment.

Findings:

At pretest, the groups did not differ in their knowledge of the HAH. At posttest, all groups had acquired significantly and substantially more knowledge of the heliport. Upon transfer to the actual Fort Rucker heliport, members of all groups were able to navigate from location to location with near zero errors upon their very first visit. Spatial knowledge was acquired in the

synthetic environment and usable upon transfer to the real-world setting.

There was no effect of the different visual display interfaces upon spatial knowledge acquired, reported presence, or reported simulator sickness. Simulator sickness was significantly and substantially reduced after 24 hours away from the synthetic environment. Presence did not correlate with knowledge acquired. There was a significant negative correlation between simulator sickness and amount of spatial knowledge acquired. There was a significant negative correlation between reported presence and reported simulator sickness.

Utilization of Findings:

Research such as this is necessary to establish that synthetic environments can be used for training military tasks where the geospecific location is crucial--tasks such as premission planning and mission rehearsal. This research shows that spatial skills learned in a synthetic environment transfer to real-world settings. Synthetic environments technology is a potentially effective instructional medium. This experiment also showed that equivalent amounts of spatial learning occurred using widely different visual display technologies. Further, the experiment showed that the use of such synthetic environment technologies for training is not without costs. Simulator sickness was a side effect of training for some soldiers.

LEARNING IN A SYNTHETIC ENVIRONMENT: THE EFFECT OF VISUAL DISPLAY, PRESENCE, AND SIMULATOR SICKNESS

CONTENTS

LIST OF TABLES

Page

LIST OF TABLES (Continued)

LIST OF FIGURES

LEARNING IN A SYNTHETIC ENVIRONMENT: THE EFFECT OF VISUAL DISPLAY, PRESENCE, AND SIMULATOR SICKNESS

Introduction

Background

Distributed Interactive Simulation (DIS). It is commonly acknowledged in the military that everything except actual combat is simulation. Simulation is generally meant to refer to one of three classes of activity, either alone or in combination (e.g., Drabczuk & Tarr, 1993; Goldiez, 1995; Singley, 1993). "Live" simulation is concerned with real equipment in the field. Field exercises at the National Training Center with soldiers and vehicles instrumented with the Multiple Integrated Laser Engagement System are an example of this class of simulation. "Constructive" simulation refers to wargames, models, and analytical tools such as Janus, TACWAR, and WARSIM 2000. These models typically run faster than real time on mainframe computers and are used to simulate large unit operations. "Virtual" simulation refers to systems and soldiers in simulators fighting on synthetic battlefields. One example of this class of simulation is the Simulation Networking (SIMNET) system wherein soldiers in simulators fight as units in a computer-generated (i.e., synthetic) environment. The Close Combat Tactical Trainer, an improved descendant of SIMNET, is expected to be fielded in 1997 (Roos, 1995). This virtual simulation system will consist of networked combat vehicle simulators to be used for collective, mission-oriented, training of armor, mechanized infantry, and cavalry troops at platoon and company level. A third example of virtual simulation is aircraft simulators, which have a relatively long history in the military (e.g., Hays & Singer, 1989; Wiener & Nagel, 1988).

Historically, one of the best reasons for the use of simulation in training has been that of cost savings. Given the current resource constrained environment, it is no surprise that the U.S. Army is vigorously exploring simulation assets for training. Examples of how simulation technology can reduce training costs abound. Atlantic Resolve, an example of a live simulation exercise, took place in October 1994 in Europe (DRG, 1995). It was the first multinational large-scale battle exercise of this type. It cost $15 million. The 1988 REFORGER exercise, by comparison, cost in excess of $60 million, not

including deployment and rail costs. Selix (1993) analyzed the costs to maintain and support a high fidelity helicopter simulator versus the actual aircraft. The MH-53J aircraft's hourly costs were $3100/hour while those of the MH-53J Weapon System Trainer (a virtual simulation) were $800-$1000/hour. Further, if one takes into consideration the high cost of today's sophisticated ammunition the comparisons between actual equipment and virtual simulation become staggering. For example, note this recent quote from BG Michitsch, the Commander of the U.S. Army's Simulation, Training, and Instrumentation Command (Roos, 1995):

> Take the cost of flying an Apache helicopter and firing its basic load of weaponry. If you fly an Apache for an hour and a half, and you fire the basic load of ammunition--Hellfire (anti-tank) missiles, 2.75-inch rockets, and 30 mm chain gun rounds--it costs about $335,000. That's in ammunition expended, fuel, and maintenance. Or you can do the same thing in a simulator for $143. (p. 25)

The three classes of simulation (live, constructive, and virtual) will be linked in the Army's current approach to simulation design called Distributed Interactive Simulation or DIS. DIS is not simply a simulator or even a family of simulators. It is a common set of protocols linking simulators together via networks to produce a common, consistent virtual world (Goldiez, 1995). DIS has been described as a shared virtual reality for all participants (Goldiez, 1995). The official definition of DIS is reported by Drabczuk and Tarr (1993) as "DIS is a synthetic environment (at one time described as the 'Electronic Battlefield') within which humans may interact through simulations at multiple sites networked using compliant architecture, modeling, protocols, standards and data bases" (p. 33). Another useful definition is given by Bell, Mastaglio, and Moses (1993):

> Distributed Interactive Simulation (DIS): The technology of linking simulators and workstations representing a diverse set of weapons platforms and combat elements over local area, wide band, and long haul networks. Linked nodes are able to operate within a shared synthetic environment and experience common outcomes from combat events. (p. 28)

In November 1994 these three types of simulations were linked in a brigade level proof-of-concept demonstration called Synthetic Theatre of War--Europe (Sottilare, 1995). This report discusses

issues and research relevant to the virtual simulation component of DIS.

Virtual reality, virtual environments, and synthetic environments. Virtual reality is sometimes defined as the experience of being immersed in an interactive, three-dimensional, computer-generated environment (e.g., Pimentel & Teixeira, 1993; U.S. Army Research Office, 1992). Other times virtual reality is defined as a computer-generated, interactive, three-dimensional environment in which a person is immersed (e.g., Aukstakalnis & Blatner, 1992; Mogal, 1993; Pausch, 1993). The term virtual environment also refers to a computer-generated, three-dimensional, interactive environment in which a person is immersed (e.g., Ellis, 1991; Mowafy & Congdon, 1994; Mowafy & Miller, 1993). The critical defining features of both terms are computer generation, immersion in a three-dimensional (3-D) environment, and interaction. In this report, a virtual environment (VE) is defined as a computer-generated, 3-D environment in which a person is immersed and with which the person can interact. The hardware and software which makes this possible is called virtual environment technology or VE technology. The computer-generated, 3-D environment itself is often called a synthetic environment or a synthetic battlefield in military publications (e.g., Bell et al., 1993; Goldiez, 1995; Singley, 1993).

Immersion is an important concept in this literature. The experience of immersion was described by Aukstakalnis and Blatner (1992) this way:

> Being immersed means being surrounded by something; everywhere you look, it's there...To create a sense of immersion in a virtual environment, we must be able to surround ourselves with various stimuli in a manner that makes sense and that follows rules similar to those of the real world. That is, when you turn your head to the left, you see the objects to the left of you. When you walk forward, you get closer to the objects in front of you. These are elementary features of our sense of being immersed in an environment; and when you're in a virtual environment, you expect the same results. (p. 27)

The typical mode of immersion is via a head-tracked, head-mounted (or helmet-mounted) display. Wherever the participant looks, the computer renders the appropriate view to be seen in

real time or near real time. Sometimes, 3-D sound is provided through earphones. Sound appears external to the participant and appears to move with movements of the participant or of the virtual sound source. The participant can interact with the virtual environment. Interaction may be limited to locomotion through the environment (also called surrogate travel) or may include locomotion plus interaction with virtual objects (e.g., push virtual buttons, grasp and move virtual objects, doors open upon proximity, etc.).

When one is immersed in a synthetic environment and can interact with that environment one experiences presence. Presence is the experience of feeling that one is physically present within the computer-generated environment. Sometimes this experience is informally referred to as "being there."

Virtual environments and training: General. There are many capabilities inherent to VE technology which may prove valuable for training. Many of these capabilities were described by Johnson and Wightman (1995). One of these is the VE itself. Any environment that can be programmed into a database is capable of being visualized by the participant. Real world constraints do not need to apply to these created worlds. For example, virtual environments exist for the visualization of objects such as molecules which are normally too small to be seen. Virtual environments exist for the visualization of objects such as galaxies which are normally too large, too dim, and too far away to be seen. Many examples of created worlds exist (see Aukstakalnis & Blatner, 1992; Ellis, 1991; Krueger, 1991; Pimentel & Teixeira, 1993; Rheingold, 1991).

The value of the synthetic environment itself is particularly important to the U.S. Army. After all, the mission of any Army is to take and hold land. Since the Civil War, however, the U.S. Army has always found itself transported to enemy-held terrain to fight. This means that the advantage of terrain knowledge has always been with the adversary. Terrain information from maps, satellite photos, and reconnaissance patrols has been used historically in an attempt to ameliorate this disadvantage. It is within this context that the U.S. Army's eagerness to explore the technical possibilities of using synthetic environments for premission planning and mission rehearsal makes sense (e.g., Bell et al., 1993; Landry, 1994; Moshell, Blau, & Dunn-Roberts, 1993; Yuhas, 1993). In principle, the technical capability already exists to download terrain

databases from satellite sensor systems to simulator networks. This means that combat arms units can train in synthetic representations of the enemy terrain that they are expected to fight on prior to embarkation.

Though less dramatic, there are other advantages of synthetic environments for training. Synthetic environments make it possible for units to train on terrain other than their own local ranges. With the addition of advanced simulator networks (see DIS above) large-scale collective training exercises can be performed without the expense of getting all the players and their equipment physically aggregated onto the same range.

However, all these exciting technical possibilities aside, there are some fairly prosaic behavioral science issues that must be addressed alongside the fielding of these simulation networks. Will skills learned in a virtual environment transfer to the real world? Which skills will and which will not? Specifically, it is generally assumed that terrain familiarization which takes place in a synthetic representation will transfer to the geospecific location. Will this transfer occur? Is the experience of presence, which is so important a research issue in the field of virtual reality, necessary for learning to occur in the synthetic environment? Are there any serious side effects or aftereffects associated with training in synthetic environments? Certainly the issue of simulator sickness becomes increasingly important as simulators become increasingly relied upon for individual and collective training. Earlier research performed by the U.S. Army Research Institute (ARI) has begun to uncover answers to some of these questions. The current research is a continuation of this line of inquiry.

Spatial learning in virtual environments. Becoming familiar with an environment through active exploration involves learning a mental model or spatial representation of that environment. It is this spatial representation which is used by people when finding their way around a familiar environment. A spatial representation includes landmarks, routes, and configuration knowledge (e.g., Witmer, Bailey, & Knerr, 1995). Landmarks are unique objects at specific locations in the environment. Routes involve the procedural knowledge required to get from initial locations to goals following specific sequential paths. Configuration knowledge is map-like knowledge. It is a representation which relates the landmarks and routes to one another. It includes the overall pattern or gestalt, the spatial

relationships among objects, relative placement of objects, and approximate distances among them.

Regian, Shebilske, and Monk (1992) have suggested that virtual environment technology may be particularly well-suited as an instructional medium for the training of spatial knowledge. This is because VE technology preserves both the visual-spatial characteristics of the real world, and the linkage between actions (motor responses) and effects. That is, VE technology allows participants to see what is to their left by turning their head to look left. If a participant wants to see what is behind a building he or she can move around the side of the building and look behind it. (These affordances provided by VE technology have been mentioned above, and are part of the defining characteristics of the medium.)

In a preliminary experiment, Regian et al. (1992) showed that participants were able to use the medium of virtual reality to learn the configuration of a virtual building. They provided evidence that spatial learning can take place using a VE. Unfortunately, however, this experiment did not include a transfer test in an identical real world building. So the implications of these results for Army training are not clear.

A likely military mission for which VE training may be a useful form of mission rehearsal would be hostage rescue from a known building by special operations forces. VE technology could be used to familiarize soldiers with the interior of the building prior to the mission. Research relating to this mission has been conducted by Witmer et al. (1995). The task was to learn a complex route through a large building. Participants were trained in one of three groups (i.e., actual building, VE building, and symbolic) and then transferred to the actual building. Participants trained in the actual building performed best on the transfer test, followed by participants trained in the virtual building. The participants trained using symbolic techniques (i.e., written directions, photographs) performed the worst on the transfer test. This experiment provided evidence that participants were able to learn interior route information using VE technology and transfer this knowledge to the actual building. That is, spatial knowledge acquired in a virtual environment transferred to the real world.

Johnson and Wightman (1995) had a group of soldiers use VE technology to familiarize themselves with a geospecific, external terrain location. They explored the virtual representation of a large Army heliport that they had never previously visited. A control group used the same VE equipment and procedures to explore an irrelevant external terrain location. Both groups were later tested on their knowledge of the landmarks, routes, and configuration of the heliport. The results demonstrated unambiguously that the soldiers in the heliport group were able to acquire spatial knowledge in the VE and then use this information when they were transferred to the actual airfield. The addition of the control group ruled out the possibility of these results being obtained by some experimental artifact or confounding.

Thus, there is evidence that people can acquire visual-spatial information of both interior and exterior locations using VE technology as the medium of instruction. Further, this knowledge, once acquired, will transfer to the real world. That is, a valid cognitive representation of real world space can be developed using virtual environment training media. Later research will need to address the issues of how best, or most cost effectively, to provide this training. What VE technologies are most training effective? What instructional strategy is most training effective? To date, both in research and in demonstrations, the pedagogical techniques used have tended toward free play and exploration. Would a more structured strategy produce greater training effectiveness?

Presence in virtual environments. The sense of being physically present within a computer-generated space--the feeling of actually being there when one is immersed in a virtual environment--is called presence. What are the necessary and sufficient conditions required to create this experience of presence? At the moment this is an area of intense speculative and research interest within the community of those interested in virtual reality and virtual environments. For a thorough discussion of this issue see Witmer and Singer (1994).

The popular scientific literature is replete with speculation as to the conditions which may cause or facilitate presence (e.g., Aukstakalnis & Blatner, 1992; Pimentel & Teixeira, 1993; Rheingold, 1991). A listing of these conditions includes: large field of view (FOV), stereoscopic display, high resolution display, rapid update rate, eye tracking, head

tracking, head-mounted display, 3-D sound, engaging imagery, high image complexity, and interactivity. Credible scientific researchers have also acknowledged the likelihood that among the sensory factors which cause the experience of presence must be a visual display which includes a wide FOV, a high resolution, and a rapid update rate (e.g., Held & Durlach, 1992; Psotka & Davison, 1993; Psotka, Davison, & Lewis, 1993). Clearly, in the absence of scientific evidence to the contrary, it is intuitively reasonable to suppose that a visual display such as a helmet-mounted display which presents a stereoscopic, high-resolution, wide-FOV image and whose image is updated rapidly should be able to create the experience of presence.

As an interesting aside, note that most sensory factors considered to be necessary for an experience of presence are visual. A strong argument can be made for the inclusion of auditory sensory information in this list--both foreground signals and background noise (Gilkey & Weisenberger, 1995). Research in this auditory domain is being actively pursued (e.g., Wenzel, 1992).

The professional scientific community has recognized that before definitive empirical research can be performed to determine the parameters which produce presence, a useful measure of presence must first be devised (e.g., Held & Durlach, 1992; Sheridan, 1992). Responding to this need, two independent groups of ARI scientists have developed instruments designed to measure the reported experience of presence in virtual environments. These are the instruments developed by Psotka and Davison (1993) and by Witmer and Singer (1994). The presence instrument developed by Psotka and Davison is called the Total Immersion Scale and that of Witmer and Singer is called the Presence Questionnaire.

It has been reported anecdotally that there are wide differences in how people respond to immersion in a VE. Researchers in this field notice such differences among their research participants on a regular basis. For some, the virtual environment is "oh, wow" while for others it is "ho hum." Clearly, among those factors which influence the experience of presence in a VE are individual differences. Both of the ARI research teams mentioned above were aware of this and both independently developed instruments to measure individual differences in the predisposition to experience presence. Psotka and Davison (1993) called their instrument the Susceptibility

Questionnaire. Witmer and Singer (1994) called theirs the Immersive Tendencies Questionnaire.

Simulator sickness in virtual environments. Simulator sickness was first documented in a report of a helicopter trainer in 1957 (Kennedy, Berbaum, Smith, & Hettinger, 1992; Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992). Flight simulators have since 1957 been reported to produce symptoms such as nausea, dizziness, disorientation, eyestrain, and cold sweating. These symptoms are similar to those of motion sickness but with less vomiting and more eyestrain (Kennedy, Berbaum, & Lilienthal, 1992; Kennedy, Fowlkes, & Lilienthal, 1993; Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992).

In addition to the discomforts experienced during simulator use, there are also residual aftereffects of simulator exposure. These aftereffects include locomotor ataxia, interference with higher-order motor control, physiological discomfort, visual aftereffects, and flashbacks (e.g., Kennedy, Berbaum, & Lilienthal, 1992; Kennedy, Berbaum, Smith, & Hettinger, 1992; Wright, 1995). These aftereffects have been verified to persist for hours, days, and--rarely--a week or more (e.g., Wright, 1995).

It has long been generally accepted within the scientific community that simulator sickness is caused by (1) a mismatch between the types of sensory information presented by the simulator, and/or (2) a mismatch between the sensory information presented by the simulator and that sensory information presented by the aircraft (and "remembered" by the experienced pilot's nervous system). An example of the former cause would be a case where the visual cues to motion presented by the simulator do not match the proprioceptive cues to motion presented by that simulator. There are many such perceptual mismatches in current flight simulators (Wright, 1995). An example of the latter cause would be when an experienced pilot is flying a simulator whose motion cues do not match the motion cues presented by the aircraft being simulated. It is well known that experienced pilots are at a greater risk for simulator sickness than newly trained pilots (e.g., Kennedy, Berbaum, & Lilienthal, 1992; Pausch, Crea, & Conway, 1992). This theory is often called the perceptual conflict theory or the cue conflict theory (e.g., Kennedy, Berbaum, & Lilienthal, 1992; Kolasinski, 1995; Wright, 1995).

The Simulator Sickness Questionnaire was developed and validated for the purpose of measuring simulator sickness (Kennedy, Lane, Berbaum, & Lilienthal, 1993). This instrument is a checklist of 16 symptoms. It is easy and quick both to administer and to score. It allows for the measurement of three subscales entitled Oculomotor (e.g., eyestrain, difficulty focusing, blurred vision, headache), Disorientation (e.g., dizziness, vertigo), and Nausea (e.g., nausea, stomach awareness, increased salivation, burping). The three subscales are combined to produce a Total Score.

Clearly, the research area of simulator sickness is a mature one. It is by no means stable and uninteresting, however. As new technologies change the simulator market new sources of simulator sickness emerge. In this regard, it can be expected that the expansion of the simulator market to encompass individual combat arms training, networked collective training, and virtual reality entertainment systems will result in an unprecedented increase in the incidence of simulator sickness. This potential for future discomfort has by no means gone unnoticed. Aviation-based simulator researchers have published representative findings (Kennedy, Berbaum, & Lilienthal, 1992) as well as research techniques for the identification of future sickness-producing systems (Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992). Literature reviews drawn from aviation-based simulator sickness research have been written by researchers in the field of virtual environments (Biocca, 1992; Kolasinski, 1995; Pausch, Crea, & Conway, 1992). A special working group of the Defense Modeling and Simulation Office (DMSO, 1994) was formed to examine helmet-mounted display technology both to define the extent of the problem and to determine solutions. The term "virtual reality sickness" has been coined.

Research Issues

This experiment addressed a number of research issues which are relevant to training soldiers using VE technologies. Participants in this experiment were asked to become familiar with the virtual representation of an actual, geospecific location. They all explored the identical synthetic environment for the same period of time. Later they were given a series of tests of what they had learned. The three experimental groups differed only in the characteristics of the visual display devices they used to view the VE during their exploration. Two groups used a high-resolution, helmet-mounted display varying

only in FOV. The third group used a lower-resolution, stationary, wide-screen display. (Details of the design and method will follow later in this report.) The issues addressed in this research were three major categories of issues which are critical to the implementation of VE technology for training--spatial learning, presence, and simulator sickness.

- Will participants be able to learn the spatial information present in the VE and transfer this knowledge to the actual, physical location?

- Will the differences in visual display technology affect this learning? That is, does a high-resolution, wide FOV, helmet-mounted display facilitate visual-spatial learning?

- Will the differences in visual display technology affect the experience of presence in the VE? That is, does a high-resolution, wide-FOV, stereoscopic, helmet-mounted display produce more presence than other display types?

- Will individual differences in predisposing factors correlate with increased presence?

- Will the amount of presence correlate with the amount learned in the VE? That is, does presence improve learning or is it merely an interesting epiphenomenon?

- Will the magnitude of simulator sickness vary as a function of visual display? Will a helmet-mounted display produce more simulator sickness than a conventional, stationary, wide-screen display? Will a wide-FOV, helmet-mounted display produce more sickness than a narrow-FOV, helmet mounted display?

- Will the magnitude of simulator sickness decrease over the 24-hour period between immediate report and next day report?

- Will the magnitude of simulator sickness affect the amount learned in the VE? That is, does simulator sickness affect training in a VE?

- Will simulator sickness affect the magnitude of the presence experience in a VE?

Domain

The spatial task performed by participants in this experiment was to use VE technology to become familiar with an exterior, geospecific location. This meant learning the landmarks, the routes, and the configuration of the 3-D space. This required choosing some physical location to be modeled in the virtual environment. The domain chosen for virtual familiarization was the Hanchey Army Heliport (HAH) located on Fort Rucker. This heliport was chosen for a number of reasons. First, one potentially valuable application of VE technology to Army Aviation is to familiarize pilots with the physical features and flight pattern information of an airport prior to their arriving there in an aircraft. Second, since the HAH is located at Fort Rucker it is easily accessible for tests of transfer. Third, the HAH is a basing field for the AH-64A Apache helicopter. ARI's Simulator Training Research Advanced Testbed for Aviation (STRATA) facility at Fort Rucker is currently configured as an Apache helicopter. Hence, the HAH virtual model could have other research uses in the future. This was the same domain used by Johnson and Wightman (1995).

Instructional Strategy

The instructional strategy used for familiarization training in this experiment was self-guided exploration. Participants were free to travel about wherever they chose in the VE and to use their own techniques to become familiar with the physical features and flight pattern information present there. This strategy was chosen for two reasons. First, it was an anchor point along the dimension that varied from structured, lockstep, group-based instruction to unstructured, self-guided, individual-based instruction. Second, both past VE training (e.g., SIMNET; Alluisi, 1991) and projected VE training (e.g., DIS; Vaden, 1993) have emphasized free-play learning.

Three Group, Pretest-Posttest, Experimental Design

Three independent groups of experimentally naive soldiers were run. Soldiers were randomly assigned to Conditions 1, 2, or 3. The only difference between the groups (i.e., the independent variable) was the specific visual display conditions with which they viewed the HAH domain. Condition 1 was a high-resolution, helmet-mounted display providing a wide FOV. Condition 2 was the same high-resolution, helmet-mounted display configured to

present a narrow FOV. Condition 3 was a lower-resolution, stationary, wide-screen display presenting a wide FOV. Members of all three groups were pretested on their knowledge of the HAH, then allowed self-guided exploration of the virtual Hanchey environment, then posttested on their knowledge of the HAH. In addition, all participants completed questionnaires assessing their predisposition to experience presence prior to their exploration of the VE. All participants completed a questionnaire assessing their experience of presence upon exit from the VE. Finally, all participants completed a checklist measuring symptoms of simulator sickness both immediately upon exit from the VE and 24 hours later.

Hypotheses

Certain hypothesized relationships were expected from prior research, published speculation, and the logic of experimental design. These relationships are listed below by category.

Knowledge of the Hanchey Army Heliport. There was not expected to be any significant differences among the three visual display conditions at pretest. Posttest performance was expected to be significantly better than pretest performance. Significant differences were expected among the three display conditions on all posttests, with performance on Condition 1 being best.

Presence. There was not expected to be any significant differences among the three visual display conditions on either of the two instruments assessing predisposition toward experiencing presence. Significant differences were expected among the three display conditions on reported experience of presence, with greatest presence being reported for Condition 1. The two predisposition questionnaires were expected to intercorrelate positively and significantly. Each of the two predisposition instruments was expected to correlate positively and significantly with measured presence.

Simulator sickness. Measured simulator sickness was expected to be significantly more severe immediately upon exit from the VE than 24 hours later. Significant differences were expected among the three display conditions on measured simulator sickness, with reported sickness greatest for Condition 1.

Presence and knowledge. Significant, positive correlations were expected between both predisposition instruments and the posttest measures of HAH knowledge. A significant, positive correlation was expected between measured presence and all posttest measures of knowledge of HAH.

Simulator sickness and knowledge. Reported simulator sickness was expected to correlate negatively and significantly with amount learned about HAH in all posttest measures of knowledge.

Presence and simulator sickness. Magnitude of reported presence in the VE was expected to correlate negatively and significantly with magnitude of reported simulator sickness.

Simulator Training Research Advanced Testbed for Aviation

The experiment was conducted using ARI's STRATA. STRATA is a sophisticated research simulation facility designed to address issues pertaining to simulator training effectiveness and the training system complexity needed to accomplish specific training objectives. It is modular and can be reconfigured to represent different training devices with different visual, motion, cockpit, and aeromodel subsystems. For a detailed description of STRATA see Kurts and Gainer (1991). For a description of research conducted to validate STRATA see Stewart (1994). Stewart, Wightman, and Gainer (1993) discuss future research planned to be conducted in STRATA. A brief review of the first dozen research efforts performed using STRATA is available from ARI (ARI, 1995). The immediate objective of the research program is to employ STRATA to address four major issues: (a) the minimal level of fidelity required to meet training objectives; (b) the most effective (in terms of outcome and cost) use of flight simulation technology to attain and sustain combat readiness; (c) the most effective ways of defining the use of new operational equipment, tactics, techniques, and procedures in a realistic threat environment; and (d) requirements for a new generation of low-cost, modular, transportable, simulation systems. Future efforts will center on the definition of training strategies for unit level networked training systems using the recently developed inhouse, multiplayer, STRATA network.

Method

Participants

Thirty participants were randomly assigned to the three conditions of this experiment. Ten were assigned each to Conditions 1, 2, and 3. All participants were soldiers from aviation units at Fort Rucker. All were volunteers and all signed the Volunteer Agreement Affidavit (DA Form 5303-R, May 88). Criteria for selection to this experiment were that participants be soldiers from Fort Rucker who had never visited the Hanchey Army Heliport. Gender, rank, and military occupational specialty were irrelevant for this experiment and were not included as criteria for selection. Table 1 presents a demographic summary of the participants in this experiment.

Table 1

Demographic Description of Experimental Participants*

Gender		Rank	
Male:	27	Officers:	15
Female:	3	CPT	(1)
		1LT	(1)
Age (years)		2LT	(13)
Mean:	25.77	Warrant Officers:	13
Median:	25	WO1	(13)
Range:	22 - 30	Enlisted:	2
		SGT	(1)
Aviator		SPC	(1)
Yes:	26		
No:	4		

* N = 30

Apparatus and Materials

A general description of STRATA. STRATA is currently configured as an AH-64A Apache helicopter. There are two separated cockpits, pilot and copilot-gunner, constructed from salvaged AH-64A cockpits. Both cockpits contain fully functional and integrated flight instruments, sensors, displays, and mission

packages. Flight controls are linked between the cockpits. Flight controls produce accurate force feedback. The simulator flies as an Apache due to accurate aerodynamic modeling. Motion cueing is provided to both cockpits by means of hydraulically actuated pneumatic G-seats. The cockpits communicate via intercom. Both cockpits are continuously ventilated with cooled air.

Imagery for both out-the-window views as well as all sensor displays is provided by an Evans and Sutherland ESIG-1000 image generator. This image generator uses 11 channels distributed over three eyepoints (pilot, copilot-gunner, and sensor). There are two infrared post processors for both Apache forward-looking infrared radiation (FLIR) sensor displays. Image update rate is 60 Hz.

In the pilot cockpit, out-the-window scenes are presented via a stereoscopic, fiber optic helmet-mounted display (FOHMD). This display presents four channels of visual information--left and right background and left and right inset. The instantaneous background FOV is 127 degrees horizontal and 66 degrees vertical. However, since the helmet employs an infrared head tracking system and presents imagery wherever the pilot looks, the effective field of regard is 360 degrees. Infrared eye tracking positions the left and right high resolution insets at the center of the viewer's gaze. These insets subtend 24 degrees horizontal and 18 degrees vertical (see Figure 1). Measured resolution of the background displays is 5.0 arcminutes while that of the insets is 1.5 arcminutes. Each left and right background displays 512 lines, 524,000 pixels, and 1200 polygons. Each inset displays 1024 lines, 1,048,000 pixels, and 1200 polygons. Luminance is greater than 35 footlamberts. Contrast ratio is 50 to 1. The FOHMD weighs five pounds but part of this weight is supported by three wires which, though attached to the structure of the simulator, allow full freedom of movement. (The standard Apache flight helmet, the Integrated Helmet and Display Sight Sub-system or IHADSS, also weighs five pounds.) A helmet is custom fitted and optically calibrated to each participant.

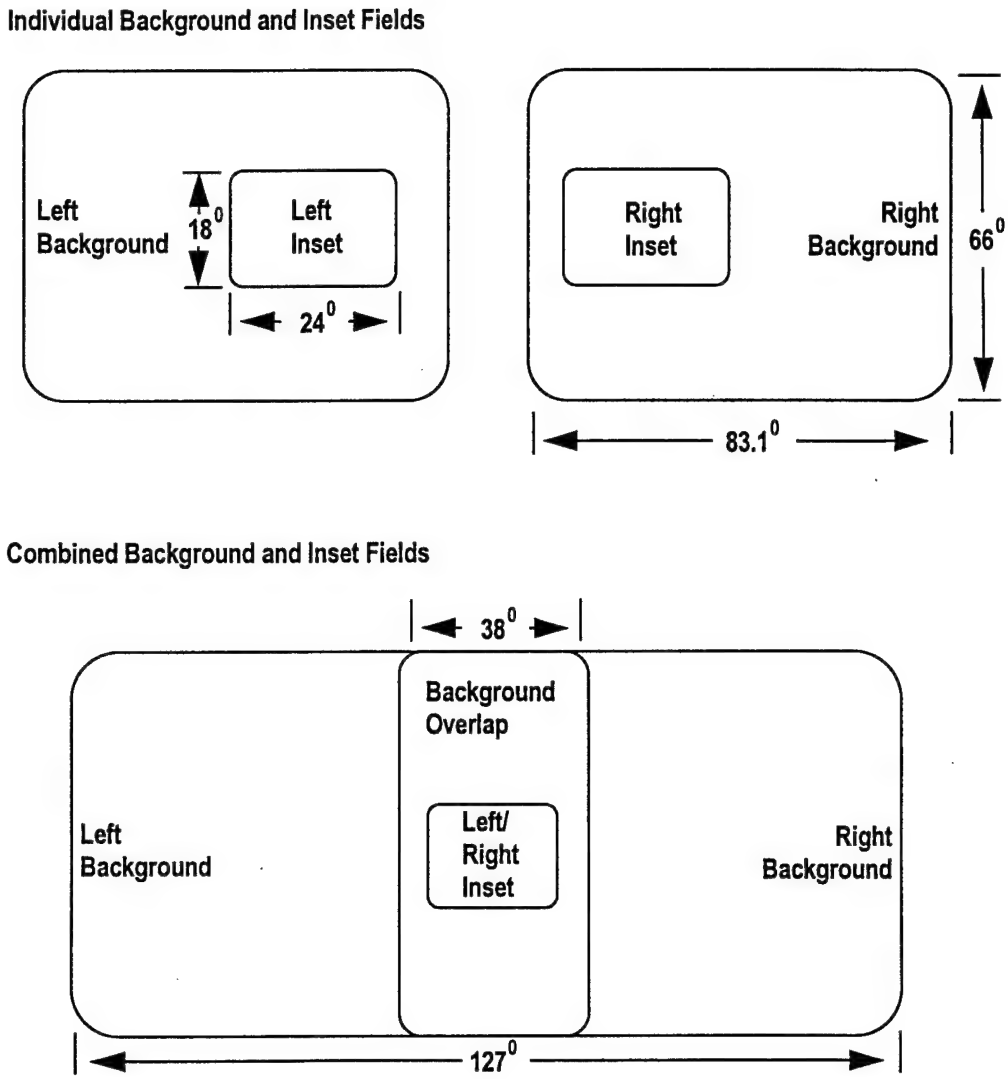


Figure 1. Schematic diagram of the background and inset fields of the fiber optic helmet-mounted display. (The relative scale among the objects is accurate.)

In the copilot-gunner cockpit, the out-the-window scenes are presented on the alternate display. This display presents three integrated channels of visual information--left, right, and center--on three contiguous, flat, rear-projection screens. Field of view is 174 degrees horizontal and 45 degrees vertical. Measured resolution of this display is 3.5 arcminutes. The left and right screen each display 946 lines, 968,704 pixels, and 1200 polygons. The center screen displays 946 lines, 968,704 pixels, and 2000 polygons. Maximum, focused light output is 500 lumens.

All control of the simulator is exercised from the Experimenter-Operator Station (EOS). An experimenter can initiate simulator scenarios, monitor participants in their cockpits, communicate with participants over the intercom, and observe via repeater displays the visual scene presented to either cockpit. The Interactive Tactical Environment Management System is used to create scenarios, control multiple intelligent synthetic players (both friendly and hostile), control weapons, terrain, and weather. The Blue-Red Team Station allows the experimenter to control any player in the scenario from the EOS. There is also a Database Management System and Data Recording and Analysis Station, which support tactical scenario generation and performance measurement. A visual database modeling workstation can be used to modify existing visual databases and create new ones.

<u>Experiment-specific features of STRATA</u>. Both cockpits were used (sequentially) in this experiment. No flight intruments or flight controls were used. They were covered by black blankets. Cockpit lights and power were turned off. The G-seat was not used. No vestibular or proprioceptive cues to motion were present in this experiment. Ventilation remained on.

Two joysticks were attached to each cockpit's seat at a comfortable armchair height--one on the left and one on the right. The left joystick controlled up and down movement. The right joystick controlled forward and backward movement as well as left and right turns. A button on the right joystick was the reset button. Pushing this button caused the image generator to reposition the participant to a particular location in each virtual environment.

The three conditions of the experiment each used a different visual display. Conditions 1 and 2 used the FOHMD in the pilot cockpit. Condition 3 used the alternate display in the copilot-gunner cockpit.

Condition 1 employed the stereoscopic FOHMD for the presentation of all visual information while in the VE. The FOHMD was used in its standard, wide FOV configuration (127 degrees horizontal by 66 degrees vertical). Condition 1 was also called the Helmet Mounted Display-Wide FOV Condition or HMD-W.

Condition 2 also employed the stereoscopic FOHMD for the presentation of all visual information while in the VE. The FOHMD was used in a narrow FOV configuration. Field of view was set to 40 degrees horizontal by 30 degrees vertical. Everything except FOV was identical between Conditions 1 and 2. All helmet and optical hardware remained constant across Conditions 1 and 2. The FOV was made narrow using software. Database modelers created a large, black polygon attached to the helmet of the participant. This polygon had an aperture of 40 degrees by 30 degrees in the center of the visual field. This "polygon-with-porthole" was attached to the helmet and remained centered in the visual field as the participant moved his or her head. The VE was only visible through this narrow aperture in the black polygon. Condition 2 was also called the Helmet Mounted Display-Narrow FOV Condition or HMD-N.

For both Condition 1 and Condition 2 head tracking was enabled. The combination of the infrared head-tracking system, the rate sensing hardware mounted on the helmet, the prediction algorithms, and a 60 Hz update rate produced a virtual experience with no perceptible head tracking delay. Eye tracking was not used in this experiment. Both the left and the right high resolution insets were fixed forward in the center of the visual field.

During the experiment, a large black curtain was drawn completely around the pilot cockpit for Conditions 1 and 2. This served to prevent ambient light from the dimly lit simulator bay from reaching the cockpit. Once seated in the cockpit, the only light was that of the virtual scene displayed by the FOHMD. Participants were completely immersed in the VE and could view the environment by looking in any direction. Participants were not a disembodied eyepoint, however. When looking down, participants could see the black virtual carpet on which they

were seated. This virtual carpet covered the space immediately under their chair and feet being 2.5 feet wide by 3.0 feet long. It was this virtual carpet which could be made to fly throughout the VE under participant control by manipulation of the left and right joysticks.

Condition 3 employed the stationary, flat-panel, wide-screen display in the copilot-gunner cockpit for the presentation of all visual information while in the VE. This display was used in its standard configuration. The FOV for this display was 174 degrees horizontal by 45 degrees vertical. Condition 3 was also called the Wide-Screen Display or WSD.

The WSD used in Condition 3 was a stationary, not a helmet mounted, visual display. Thus, no head tracking was required. Nonetheless, a helmet was individually fitted and optically aligned for each participant--even those in Condition 3. For purposes of experimental control, all participants were treated identically and all participants wore a fitted helmet during their explorations of the VE. All helmets were identical, except that in Condition 3 there was no visual display hardware attached.

Unlike the pilot cockpit, the copilot-gunner cockpit used in Condition 3 was not enclosed by a curtain. This cockpit sat by itself in the simulator bay partially surrounded by its own wide-screen display. During the experiment, lighting in the simulator bay was kept at a very low level. The WSD was not fully immersive. Participants who looked far enough up, down, left, or right would leave the visual field of the VE. There were no physical constraints or procedural admonitions to prevent this occurrence.

During the experiment the visual displays seen by the participant were monitored continuously by the experimenter from repeater displays at the EOS. The intercom channel was also continuously monitored by the experimenter over earphones at the EOS. Finally, both cockpits were monitored via video cameras by the experimenter at the EOS.

<u>Virtual environments--Hanchey Army Heliport and Arizona</u>. Two virtual environments were used in this experiment--the Hanchey Army Heliport environment and a section of the Arizona environment near the town of Mesa. The HAH environment was created for this and related research. The Arizona environment

used in this research was one terrain module taken from the Arizona database. The entire state of Arizona is available in this database and is the baseline database used in STRATA.

The Hanchey Army Heliport virtual environment (HAH-VE) is an accurate, fullscale representation of the actual, physical HAH located on Fort Rucker. The HAH-VE measures 0.72 miles in east-west orientation and 0.52 miles in north-south orientation. The HAH-VE is located in the center of a flat, green, terrain square measuring 40.34 miles on a side. Nothing is visible in the green expanse beyond HAH-VE.

Priority for inclusion in the HAH-VE went to large, permanent or semipermanent, exterior features which identify HAH and to features which are relevant to the flight training mission of the heliport. That is, features were included if they were exterior, large, relatively permanent, distinctive, or important to the flight mission of the heliport. If features were judged to be critical either for identification, navigation, or flight safety they were included.

Considerable time and effort were expended to acquire the basic physical and flight pattern knowledge required to model Hanchey. Multiple visits to HAH were undertaken by the database modeling and research staff. Subject matter experts were consulted. Defense Mapping Agency data were acquired. Maps were analyzed. U.S. Army Aviation Center (USAAVNC) flight regulations were examined. Measurements were made of all permanent and semipermanent structures at HAH. Videotape and photographic records were made of the entire heliport and all structures both from the ground and from the air.

A two-dimensional, bird's eye view of the largest physical features incorporated in the HAH-VE is presented in Figure 2. Objects presented in this diagram are drawn to scale. This figure is presented with north at the top. The HAH is roughly "T" shaped. The long axis of HAH is oriented generally east-west and is presented left-right in the figure. The shorter axis of Hanchey is oriented generally north-south and is presented top-bottom in the figure. The HAH is situated on a plateau with the ground surrounding the flat tarmac sloping gently away. This is also modeled in the virtual Hanchey where the stem of the "T" (the HAH "panhandle") slopes downhill to the south.

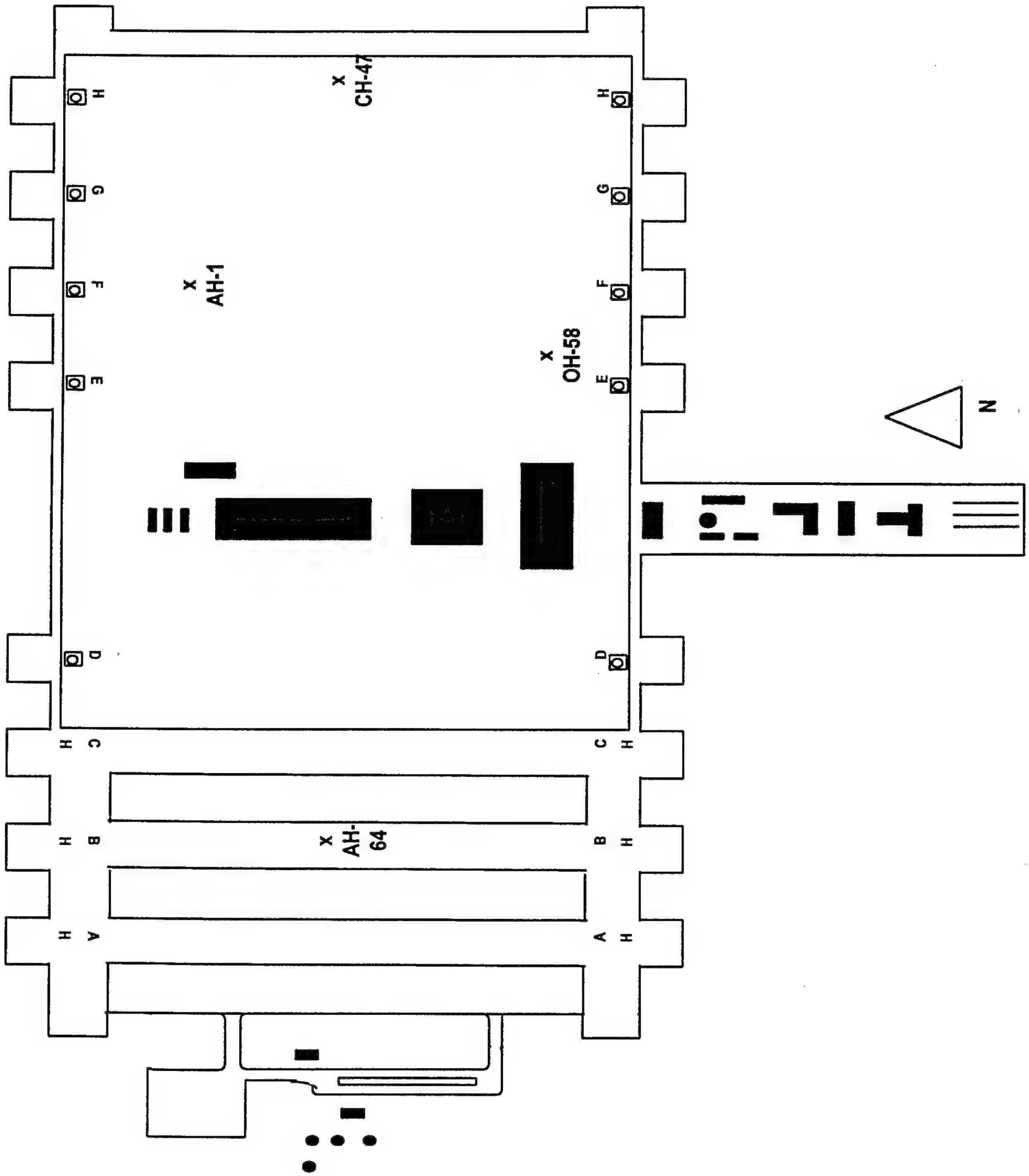


Figure 2. Scale diagram of largest physical features present in the Hanchey Army Heliport virtual environment when viewed from above.

All objects in the virtual Hanchey environment were modeled to actual size and presented in their actual locations. Colors were tuned to match the colors recorded in photographs and on videotape, where feasible. All signs and logos were texture mapped onto buildings in their correct positions.

Among the physical features modeled in the HAH-VE were all 19 helipads (including one VIP pad), all correctly designated, complete with all aircraft parking ramps, taxi lanes, and overrun areas. All 30 permanent or semipermanent buildings were modeled, including three large hangars, Cobra Hall, Chinook Hall, classroom buildings, storage buildings, the fire station, the operations building, the snack bar, and the guard shack. Critical flight related structures were modeled, including the control tower, the beacon tower, the antenna pole, all three windsocks, and all four fuel tanks. Miscellaneous, distinctive objects were also modeled, including two fire trucks, two natural gas tanks, two large dumpsters, one water tank, one satellite receiver dish, one soft drink machine, and all paved automobile parking lots. Some buildings had large, distinctive signs or logos mapped onto them. The Apache hangar had two large Apache logos--one facing east and one west. The Chinook hangar had a large field elevation sign facing east. The Kiowa hangar had a large "Warrior Country" logo and a large field elevation sign both facing south. Chinook Hall had its "Chinook Hall Windjammers" logo complete with CH-47 silhouette facing east. Cobra Hall had its large, distinctive "Cobra Hall" logo complete with green cobra snake on a red background facing south. Opposite the snake and facing south, Cobra Hall also had its large, distinctive "Warrior" death's head in black and red.

Included among the physical features of the HAH to be modeled were the helicopters based there. There are four helicopter types based at Hanchey. These are the AH-64 Apache, the AH-1 Cobra, the OH-58 Kiowa, and the CH-47 Chinook. The Apache is based on the west side of HAH, while the other three types are based on the east side. Dozens of these four helicopter types are parked at Hanchey on any given day. The HAH-VE included one exemplar of each of the four helicopter types. All helicopters were parked on their appropriate side of Hanchey and in their correct orientation. The Apache was parked in row B on the west side of HAH-VE in the north-south orientation. The Cobra was parked in row F on the east side of

HAH-VE in the east-west orientation. The Kiowa was parked in row E on east HAH-VE in the east-west orientation. The Chinook was parked in row H on east HAH-VE in the east-west orientation.

During the experiment, all four helicopters cycled through their respective traffic patterns in sequence continuously. One by one each helicopter would start its rotor turning, move from its parking place to the taxi lane, taxi to its assigned departure helipad, pick up to hover, depart along its departure lane and climb to traffic pattern altitude, and then fly the crosswind, downwind, base, and final approach legs of the traffic pattern. Each helicopter would then approach and hover over its assigned landing pad, land, taxi to its assigned parking space, park in the correct orientation, and stop its rotor. At this point another helicopter's rotor would begin to turn and it would perform its traffic pattern flight sequence. This continuous cycle was performed in the order Cobra, Apache, Kiowa, Apache, Chinook, Apache, and back to Cobra, etc.

All phases of the traffic pattern from park through flight back to park were carried out in accordance with USAAVNC flight regulations. All speeds, altitudes, distances, departure lanes, and approach lanes were accurate virtual representations of the actual flight rules followed at the HAH. For example, the traffic pattern altitude for the west Hanchey pattern is 500 feet mean sea level (MSL) but 800 feet MSL for the east Hanchey pattern. The HAH field elevation is 311 feet MSL.

One of the key advantages of VE technology is the capability to make data visible. A salient virtual feature of the HAH-VE was not a physical feature of the actual HAH. A large, red, 3-D compass arrow was present in the lower center field of view. This arrow pointed to magnetic north and had a white "N" painted on it. This arrow always pointed north no matter how the participant turned the FOHMD or moved the virtual carpet. Further, there was no perceptible lag to the directional information provided by the arrow--it kept pace with all helmet or carpet movements no matter how quickly made. Being positioned in the lower center FOV, the arrow provided compass direction without blocking the visual scene.

Pushing the reset button while in the HAH-VE would immediately reposition the participant to a location in front of the southwest section of the OH-58 Kiowa hangar facing north. From this position the participant could clearly see the Warrior

Country logo painted on the side of the building. This reset location--including the view of the logo--was the same position from which the Posttest Part 2 Questionnaire was administered on the visit to the actual HAH during the experiment (see Procedure below).

STRATA did not allow participants to pass underground while in the HAH-VE. Seated with left joystick all the way down, a participant's minimum eye level was set at two feet above ground level. A participant had to look down to see whatever terrain feature was below this eye level.

The Arizona virtual environment (Ariz-VE) was located one million feet (189.39 miles) east of the HAH-VE in the same database. The two virtual environments were separated by empty space and were, of course, not intervisible. Having both the Hanchey and the Arizona environments in the same database meant that participants could be "teleported" from one to the other in a matter of seconds under experimenter control from the EOS.

The Ariz-VE was one terrain module taken from STRATA's Arizona database. This module was a square measuring 10.08 miles on a side. It was centered east of Phoenix and included part of Mesa, Arizona. The Ariz-VE contained urban, residential, and desert terrain. The three terrain types included appropriate types and densities of buildings, businesses, churches, houses, towers, playgrounds, automobiles, roads, parking lots, signs, streams, and vegetation. The Ariz-VE did not contain any aircraft or moving models.

The red, 3-D, north-pointing compass arrow was also present in the lower center FOV in the Ariz-VE. It functioned exactly the same as it did in the HAH-VE. Pushing the reset button while in the Ariz-VE would immediately reposition the participant to a location in front of a particular gasoline station in the residential terrain. As in the HAH-VE, STRATA did not allow participants to pass underground while in the Ariz-VE. Minimum eye level was again set at two feet above ground level.

Forms, questionnaires, and other measures of performance. All 30 participants completed the identical forms, questionnaires, and other measures of performance in the same order and according to the same procedures. This is described later in the Procedure section.

Participants filled out and signed the Volunteer Agreement Affidavit (DA Form 5303-R, May 88). Information in this form served to identify the participant, the research, the experimenter, the agency, and to guarantee that all participants knew they were participating voluntarily and could withdraw at any time.

Participants completed and signed the Demographic Information Form (see Appendix). This form served to provide information as to name, social security number, age, rank, unit, telephone number, aviator status, and whether they had ever visited the HAH.

The Physiological Status Information form was a slightly modified version of the Pre-Hop Physiological Status Information form developed by Essex Corporation and used by permission (Essex, no date given). This form contained six questions. It served to provide information as to the health and physiological status of participants prior to their exploration of the VE. It asked questions concerning fitness, recent illness, recent alcohol consumption, current medications, and amount of sleep the previous night.

The Simulator Sickness Questionnaire: Immediate or SSQ(I) was an unmodified version of the Simulator Sickness Questionnaire developed by Kennedy, Lane, Berbaum, and Lilienthal (1993). It consisted of a list of 16 symptoms (e.g., headache, nausea). Each symptom was followed by a list of four levels of increasing severity (i.e., none, slight, moderate, severe). Participants were requested to circle any symptoms that applied to them "right now." Participants completed this questionnaire immediately upon exit from the VE. This questionnaire was designed and validated for the purpose of measuring symptoms of simulator sickness. It was scored according to the procedures outlined by Kennedy, Lane, Berbaum, and Lilienthal (1993). Higher scores meant greater reported simulator sickness.

The Simulator Sickness Questionnaire: 24 Hours Later or SSQ(24) was a slightly modified version of the Simulator Sickness Questionnaire developed by Kennedy, Lane, Berbaum, and Lilienthal (1993). Like the SSQ(I) it consisted of the same list of 16 symptoms, presented in the same order, with the same four severity levels. Unlike the SSQ(I) it requested participants to circle any symptoms that applied to them "in the last 24 hours since leaving the simulator." Participants completed this

questionnaire 24 hours after their exit from the virtual environment. This questionnaire was meant to provide an index of residual aftereffects of simulator exposure. It was scored according to the procedures outlined by Kennedy, Lane, Berbaum, and Lilienthal. Higher scores meant greater reported simulator sickness.

The Susceptibility Questionnaire or SQ was developed by Psotka and Davison (1993). It consisted of 15 questions. Each question requested the participant to circle the most appropriate answer along a five-point, Likert-type scale. This instrument was designed to provide an index of the extent to which participants were susceptible to, or had a predisposition for, experiencing presence within a VE. The authors defined presence as the experience of being immersed in a computer-generated dataspace and feeling as if one is really there. A description of this questionnaire as well as initial research results were provided by Psotka and Davison (1993). Scoring instructions were provided by Psotka (1994). Higher scores meant greater susceptibility.

Participants were administered the Immersive Tendencies Questionnaire or ITQ (Witmer & Singer, Version 3.0, Nov 94). This questionnaire was a later version of the instrument developed, described, and validated by Witmer and Singer (1994). Scoring instructions were provided by Singer and Witmer (1995). This instrument consisted of 34 questions. Each question asked participants to indicate their preferred answer by marking an "X" along a seven-point, Likert-type scale. This questionnaire was designed to measure individual differences in the abilities or tendencies of participants to immerse themselves in a virtual environment and experience presence. The authors defined presence as the subjective experience of being in one place (there) when one is physically in another (here). Higher scores meant greater immersive tendencies.

The Presence Questionnaire or PQ (Witmer & Singer, Version 3.0, Nov 94) was a later version of the instrument developed, described, and validated by Witmer and Singer (1994). Presence was defined by Witmer and Singer as the subjective experience of being in one place (there) when one is physically in another (here). The PQ was designed to measure this experience of presence. The questionnaire contained 32 questions, each of which requested marking an "X" along a seven-point, Likert-type

scale. Scoring instructions were provided by Singer and Witmer (1995). Higher scores meant greater reported presence.

The Pretest Questionnaire (see Appendix) consisted of 14 questions assessing landmark and configuration knowledge of HAH. Questions were concerned primarily with flight related physical features of Hanchey. Questions were also asked about the helicopters based at HAH and the flight traffic patterns of east and west Hanchey. Some questions requested participants to fill in the correct answers and others were multiple choice. Participants were requested to answer each question. Guessing was permitted. Participants who did not know the answer and did not wish to guess were instructed to write "DK" for "don't know." There were 18 points possible.

The Posttest Part 1 Questionnaire (see Appendix) was identical to the Pretest Questionnaire in every way except its title. It contained the same 14 questions in the same order. Content, instructions, and scoring were identical to the description given above for the Pretest Questionnaire. There were 18 points possible.

The Posttest Part 1 Object Placement Test (see Appendix) assessed participants' configuration knowledge of the physical features of the HAH. It consisted of a diagram of the outlines of the HAH and a list of key objects to be placed in their appropriate locations on the diagram. Objects to be placed were identified with descriptive, uppercase letters. Participants were not requested to draw actual features, merely to place the appropriate descriptive letters in the appropriate locations in the diagram. This test was designed to measure knowledge of the locations of key Hanchey features, not artistic ability. There were a total of 34 objects to be placed correctly in the diagram. Guessing was permitted. If a participant did not know where to place an object and did not wish to guess he or she could leave it blank. An object was scored as being correctly placed if any portion of it was located within 0.25 inch of its correct location. There were 34 points possible.

The Posttest Part 2 Questionnaire (see Appendix) consisted of 17 questions assessing configuration knowledge of HAH. The questions concerned the physical features of Hanchey, the helicopters based there, and the traffic pattern. Some questions covered the same information as in the Posttest Part 1 Questionnaire but in a different format and context. All

questions were multiple choice. All questions were asked verbally by the experimenter and all answer options listed. Participants reported their chosen answers verbally. Participants were requested to answer all questions. Guessing was permitted. A participant who did not know the correct answer and did not wish to guess could respond "don't know." Don't know was always one of the possible answer options. There were 22 points possible.

The Hanchey Army Heliport Walking Navigation Test or Navigation Posttest (see Appendix) was administered at the heliport. It measured participants' route and configuration knowledge of the physical features of the HAH by asking them to use their knowledge to navigate from one location to another in the real world at the actual HAH. In this transfer test, participants began at an initial position and walked to a goal position while passing two waypoints in order along the route. Neither the goal nor the waypoints were visible from the initial position. Further, to get to the goal location by passing the two waypoints required following a circuitous route. After informing the participant of the goal and the landmarks to pass along the route, the experimenter followed directly behind the participant as he or she walked. Two measures of performance were recorded by the experimenter during each walk: time, in seconds, to walk from start to goal; and number of wrong turns taken.

Procedure

General. Participation in this experiment required soldiers to be scheduled for two visits to ARI on each of two separate days. Day one activities included helmet fitting and preorientation. This took less than an hour. Day two activities were the experiment proper and included experimental orientation, pretest, exploration of the synthetic environment, posttests, questionnaires, and debrief. Participation in the experiment required 4.5 hours. Two participants were run in sequence each day, one in the morning and one in the afternoon. Except for the independent variable in this experiment (HMD-W, HMD-N, WSD), all procedures were identical for all participants.

Helmet fitting and preorientation. Upon arrival at ARI, participants met with the experimenter (DJ) who checked to make sure that they had never visited the HAH, confirmed the date and time for their participation in the experiment proper, and

briefed them in general terms on the nature of the research and what would be requested of them. They were then fitted for a helmet to support the FOHMD and had the optics calibrated for their eyes. All participants had a helmet fitted and calibrated. Participants were kept naive as to their group membership. Afterward each helmet was labelled with the name of the participant and then stored in a recorded location for use during the experiment. At no time during these activities were participants allowed to enter either the simulator bay or the EOS.

Prior to exploration of the synthetic environment: Experimental orientation, questionnaires, and pretest. Upon arrival at ARI on the day of the experiment participants were briefed on the nature of the research, their place in the research, and what was requested of them. Questions were answered, where appropriate. Participants were told that there was going to be questionnaires, a pretest followed by self-guided exploration of a VE, then more questionnaires and posttests. Participants were not told that there were three groups in this experiment nor were they told their group identity.

Participants signed the Volunteer Agreement Affidavit. Then they completed and signed the Demographic Information Form. Besides providing the demographic information listed above, this form once again asked them if they had ever visited the HAH. All participants stipulated that they had not. Participants completed the Physiological Status Information form. Next participants received first the Susceptibility Questionnaire and then the Immersive Tendencies Questionnaire. Finally, they all filled out the Pretest Questionnaire of knowledge of HAH.

Exploration of the synthetic environment. Soldiers in Conditions 1 and 2 were taken to the pilot cockpit of STRATA. Soldiers in Condition 3 were taken to the copilot-gunner cockpit. All participants wore helmets. All were given a brief orientation to the simulator. Each participant was shown how to adjust cockpit ventilation and where the emergency shut-off switches were located. The participant was shown the two joysticks and their functions. Each participant was shown the air sickness bag. Those in Conditions 1 and 2 were shown the FOHMD and how to handle it without touching the optics. They were helped on with the FOHMD. Finally, a communication check was made with the experimenter seated at the EOS.

All participants were continuously monitored by the experimenter at the EOS. Experimenter and participant had an open microphone link so that during exploration of the VE the experimenter was always available to the participant. In addition, the experimenter continuously monitored the view seen by the participant via the repeaters at the EOS.

All participants were told that they were to have two exploration sessions of 30 minutes each in the HAH-VE. They were instructed to learn as much as they could about the HAH-VE because they would be asked questions later. They were reminded that they could stop for a break at any time if they wanted a rest, if their helmet developed a "hot spot," or if they began to feel uncomfortable.

Experience in the VE began at the gasoline station reset position in the Ariz-VE for all participants regardless of group. All were instructed to practice controlling their virtual carpet using the two joysticks. After three minutes of joystick control practice in this vicinity, participants were told to return to the initial location by pushing the reset button.

Participants were then teleported from the reset point in the Ariz-VE to the reset point in the HAH-VE by the experimenter at the EOS. They were told to begin their first 30-minute exploration session. All participants in all groups completed two 30-minute exploration sessions in the HAH-VE. Sessions were separated by a 10-minute break. During the break each participant was helped off with the helmet and got out of his or her simulator cockpit.

<u>After exploration of the synthetic environment: Questionnaires and posttests</u>. Directly after the second exploration session, the participant completed the Simulator Sickness Questionnaire: Immediate. This took less than one minute. Then the participant filled out the Presence Questionnaire. This took approximately five minutes. After the assessment of simulator sickness and presence, participants were administered the posttests measuring their knowledge of the Hanchey Heliport. Two posttests were given at ARI. First, participants filled out the Posttest Part 1 Questionnaire. Then they completed the Posttest Part 1 Object Placement Test.

Then each participant was taken by the experimenter to the HAH located on Fort Rucker. The participant donned opaque goggles, provided by the experimenter, prior to getting within sight of Hanchey. Opaque goggles were worn in order to guarantee experimental control of each participant's visual exposure to HAH. Upon arrival at Hanchey, the participant--still wearing goggles--was lead by the experimenter to a particular location facing the southwest section of the Kiowa hangar. Here the participant was instructed to stand still with head and eyes fixed forward. With the experimenter positioned in front of the participant, the participant removed the goggles. The experimenter read the instructions for the Posttest Part 2 Questionnaire to the participant and then administered the questionnaire. Participants were instructed to provide verbal responses to the questions read to them from the response options supplied. The experimenter circled each response on the clipboard answer sheet. The experimenter also monitored the participant to guarantee that he or she remained stationary with head and eyes pointed forward during this posttest.

Participants were next administered the Hanchey Army Heliport Walking Navigation Test. This transfer test measured participants' knowledge of the physical features of the HAH gained in the VE by asking them to use this knowledge to navigate from one location to another at the actual HAH. This test consisted of one short practice walk and one walk for data collection.

The experimenter read the instructions for the Navigation Posttest while the participant remained stationary facing the Kiowa hangar. The practice walk requested the participant to walk from the initial position at the southwest portion of the Kiowa hangar to the nearest field elevation sign which was located on the southeast portion of the same hangar. The experimenter followed directly behind the participant, with stopwatch and clipboard, recording time in seconds and number of wrong turns. The goal position (field elevation sign) was clearly visible from the initial position and, therefore, this walk did not measure the participant's knowledge of HAH. This practice walk was included to confirm that the participant understood the procedure and to position him/her appropriately for the data collection walk to follow. Neither the goal nor the waypoints for the following data collection walk were visible during this practice walk.

The Navigation Posttest walk requested each participant to walk from an initial position under the field elevation sign to the two silver natural gas tanks at the north end of the heliport, passing in order two specific landmarks, and using the shortest route without entering any buildings. Neither the goal nor the waypoints were visible from the initial position or from each other. The experimenter followed directly behind the participant recording the two measures of performance during the test walk.

A stopwatch was used to record navigation time in seconds. Recording wrong turns was accomplished with a technique similar to that of Witmer et al., (1995). When the participant made a wrong turn, the experimenter first noted this on his clipboard and then said "stop." As part of the Navigation Posttest instructions, participants knew that when they heard "stop" they should immediately choose a different direction and continue walking. None of the participants had any difficulty understanding these instructions or applying them in the test.

The Simulator Sickness Questionnaire: 24 Hours Later, postexperimental debrief, question and answer. Upon their return to ARI participants were given the SSQ(24) plus a self-addressed envelope. They were told to complete the questionnaire 24 hours later, to place it in the envelope provided, and to return it to ARI in the Fort Rucker mail. It was made clear to all soldiers that their participation in the experiment was not finished until the SSQ(24) was completed and returned. All 30 participants completed and returned this questionnaire.

Each participant was debriefed as to the nature of the research and questions were answered. No mention of the three experimental conditions or of the expected research results was made during the debrief or the later questions and answers. After releasing each participant, the goggles were cleaned with isopropyl alcohol.

Results

Scoring

Knowledge of the Hanchey Army Heliport. There were four paper-and-pencil instruments used to measure knowledge of HAH. These were the Pretest Questionnaire, the Posttest Part 1

Questionnaire, the Posttest Part 1 Object Placement Test, and the Posttest Part 2 Questionnaire. Objective keys and reliable scoring procedures were created for these four. Responses recorded on these instruments were scored individually by two scorers. Scorer DJ, being the experimenter, was aware of which group each participant was a member of during scoring. Scorer RW was blind as to the group membership of participants. As shown in Table 2 interscorer reliability was almost perfect. Scores used in later analyses were those of DJ.

Table 2

Interscorer Reliability of Scorers DJ and RW

Instrument	Correlation*
Pretest Questionnaire	$r = .99$, $p<.001$
Posttest Part 1 Questionnaire	$r = .99$, $p<.001$
Posttest Part 1 Object Placement Test	$r = .99$, $p<.001$
Posttest Part 2 Questionnaire	$r = 1.00$, $p<.001$

* Pearson Product Moment Correlation; $df = 28$

Presence. The Susceptibility Questionnaire (Psotka & Davison, 1993) was scored according to the procedures described by Psotka (1994). This resulted in a single, total score for each participant. Version 3.0 of the Immersive Tendencies Questionnaire (Witmer & Singer, 1994) was scored according to the procedures described by Singer and Witmer (1995). This resulted in a single, total score for each participant. Version 3.0 of the Presence Questionnaire (Witmer & Singer, 1994) was scored according to the procedures described by Singer and Witmer (1995). This resulted in a single, total score for each participant.

Simulator sickness. The Simulator Sickness Questionnaire developed by Kennedy, Lane, Berbaum, and Lilienthal (1993) was scored according to the procedures described by the authors. The measure used was the Total Score which is a combination of the Nausea, Oculomotor, and Disorientation subscales. Thus, a single, total score was obtained from each participant both

immediately after exploration of the virtual environment (SSQ(I)) and 24 hours later (SSQ(24)).

Analyses

All inferential statistical analyses were performed using parametric techniques as per the recommendation of Gaito (1980). All analyses employed a one-tailed rejection region because specific predictions were made. The alpha level chosen was five percent ($p<.05$) but results between a five and a ten percent probability level ($.05<p<.10$) were noted for completeness. Differences among the three conditions of the experiment were analyzed using the one-way, independent-groups, Analysis of Variance technique or F (e.g., Keppel, 1973). Differences between the same conditions and participants over time (i.e., pretest versus posttest, immediate versus 24 hours later) were analyzed using the t-test for related measures technique or t (e.g., Bruning & Kintz, 1968). All correlations were calculated using the Pearson Product Moment Correlation or r (e.g., Bruning & Kintz, 1968).

Knowledge of Hanchey Army Heliport

Knowledge differences among the conditions. The mean scores (and percent correct) for the three conditions of the experiment (HMD-W, HMD-N, WSD) on the six tests measuring knowledge of HAH are presented in Table 3. Results of the Analyses of Variance for these tests of knowledge are also presented in this table. There were no statistically significant differences among the three experimental groups in their knowledge of HAH. The three groups did not differ among themselves at pretest and the differential conditions of the experiment did not cause them to perform differentially on the five posttest measures of knowledge.

Knowledge differences pretest versus posttest. The overall mean knowledge score across all three conditions for the Pretest Questionnaire was 1.1 correct out of 18 possible or six percent correct. The overall mean knowledge score across all three conditions for the Posttest Part 1 Questionnaire was 14.8 correct out of 18 possible or 82 percent correct. This overall difference of 13.7 correct or 76 percent was statistically significant ($t(29) = 20.21$, $p<.001$). This improvement at posttest was also statistically significant for Condition 1 separately ($t(9) = 25.43$, $p<.001$), for Condition 2 separately

($\underline{t}(9) = 8.82$, $\underline{p}<.001$), and for Condition 3 separately ($\underline{t}(9) = 9.03$, $\underline{p}<.001$). Thus, there was a significant improvement in measured knowledge of Hanchey from pretest to posttest for all conditions of the experiment.

Table 3

Comparison of Scores (and Percent Correct) Among Conditions of the Experiment on Tests Measuring Knowledge of the Hanchey Army Heliport Before and After Experience in the Virtual Environment

Test	Cond 1* HMD-W**	Cond 2* HMD-N**	Cond 3* WSD**	$\underline{F}$	$\underline{p}$
Pretest Q					
Mean	0.60(3%)	1.20(7%)	1.60(9%)	0.54	$\underline{p}>.10$
$\underline{SD}$	1.20	2.18	2.54		
PT Part 1 Q					
Mean	15.50(86%)	14.00(78%)	15.00(83%)	0.51	$\underline{p}>.10$
$\underline{SD}$	1.50	4.00	3.58		
PT Part 1 OP					
Mean	25.90(76%)	26.40(78%)	28.20(83%)	0.23	$\underline{p}>.10$
$\underline{SD}$	8.35	8.65	5.53		
PT Part 2 Q					
Mean	19.50(89%)	17.60(80%)	20.00(91%)	1.05	$\underline{p}>.10$
$\underline{SD}$	2.50	5.37	2.49		
Nav PT (time)					
Mean	265.70	267.10	270.40	0.19	$\underline{p}>.10$
$\underline{SD}$	10.36	20.87	16.81		
Nav PT (errors)					
Mean	1.00	0.70	0.80	0.26	$\underline{p}>.10$
$\underline{SD}$	0.77	1.10	0.75		

* Analysis of Variance; $\underline{N}$ = 10 each condition
** HMD-W = Helmet Mounted Display-Wide FOV
HMD-N = Helmet Mounted Display-Narrow FOV
WSD = Wide-Screen Display

Presence

Presence differences among the conditions. All participants were administered both the Susceptibility Questionnaire and the Immersive Tendencies Questionnaire prior to their exploration of the virtual environment. Both questionnaires were designed to measure the extent to which people report a predilection to experience presence. All participants were administered the Presence Questionnaire immediately after their exploration of the VE. This questionnaire was designed to measure the magnitude of the experience of presence reported by people when exposed to a VE.

The mean scores for the three conditions of the experiment on these three questionnaires are presented in Table 4. The results of the Analyses of Variance are also presented in this table. There were no statistically significant differences among the groups on any of the three presence-related measures. Participants randomly assigned to different groups did not differ in their reported predisposition scores (SQ, ITQ) prior to exploring the VE. In addition, participants who explored the VE under three different visual display conditions did not show differences in measured presence (PQ) as a function of display condition.

Table 4

Comparison of Scores Among Conditions of the Experiment on Tests Measuring Both the Experience of Presence in the Virtual Environment and the Predisposition Toward Experiencing Presence

Test		Cond 1* HMD-W**	Cond 2* HMD-N**	Cond 3* WSD**	F	p
SQ						
	Mean	52.00	55.40	53.00	1.63	$p>.10$
	SD	4.12	3.47	4.63		
ITQ						
	Mean	75.60	77.50	79.60	0.24	$p>.10$
	SD	11.05	13.00	12.53		
PQ						
	Mean	109.90	111.90	114.20	0.39	$p>.10$
	SD	10.45	11.46	9.11		

* Analysis of Variance; N = 10 each condition

** HMD-W = Helmet Mounted Display-Wide FOV
HMD-N = Helmet Mounted Display-Narrow FOV
WSD = Wide-Screen Display

Correlations among the measures of presence. Since scores on the three different presence-related questionnaires (SQ, ITQ, PQ) did not differ significantly as a function of display condition (HMD-W, HMD-N, WSD), all correlations among these presence scores were performed with data collapsed across conditions (except where noted below). Both the SQ and the ITQ were designed to measure the predilection for experiencing presence. The results showed that, in fact, scores from these two instruments were significantly correlated (r = .44, df = 28, $p<.01$). Scores on the SQ did not correlate significantly with those on the PQ (r = .26, df = 28, $p>.10$). Also, scores on the ITQ did not correlate significantly with those on the PQ (r = .11, df = 28, $p>.10$). Thus, while both measures of predisposition for presence intercorrelated significantly, neither instrument correlated significantly with measured presence (with data summed over conditions).

Interestingly, the results for correlations of data summed across conditions did not accurately reflect the results for Condition 3 alone. When analyzed separately, data from the WSD condition showed a statistically significant correlation between scores on the SQ and scores on the PQ (r = .65, df = 8, p<.025). In addition, when analyzed separately, data from Condition 3 showed a statistically significant correlation between scores on the ITQ and scores on the PQ (r = .58, df = 8, p<.05). In other words, for Condition 3--and for Condition 3 only--scores on the two predisposition questionnaires did predict scores on the Presence Questionnaire. Both the size and the consistency of this relationship argues for its validity--but only for the special case of the WSD condition.

Simulator Sickness

Physiological status prior to exploration of the virtual environment. All participants completed the Physiological Status Information form prior to their exposure to the VE. All but one of the participants stated that they were in their usual state of fitness. Only one participant had been ill in the week prior to the experiment. No participant had consumed more than two alcoholic beverages during the 24 hours prior to the experiment. No participant had taken any medication during the 24 hours prior to the experiment, other than over-the-counter analgesics. All participants stated that they had received a sufficient amount of sleep the night before the experiment. The mean amount of sleep reported by the participants on the night before the experiment was 7.5 hours (SD = 1 hour). No participant listed any comments concerning his or her physical state which would affect performance during the experiment. All participants, in short, appeared to be physically fit and ready to take part in the experiment.

Simulator sickness differences among the conditions. All participants completed the Simulator Sickness Questionnaire, both immediately after their exploration of the virtual environment (SSQ(I)) and 24 hours later (SSQ(24)). The mean SSQ scores for all three conditions of the experiment for both administrations of the questionnaire are presented in Table 5. The results of the Analyses of Variance are also presented in this table. There were no statistically significant differences among the conditions on either the immediate administration or the later administration. Thus, the three different visual display conditions did not produce a significant difference in reported

simulator sickness either immediately after exposure to the VE or later.

Table 5

Comparison of Scores Among Conditions of the Experiment on Tests Measuring Simulator Sickness Both Immediately After Exposure to the Virtual Environment and 24 Hours Later

Test	Cond 1* HMD-W**	Cond 2* HMD-N**	Cond 3* WSD**	*F*	*p*
SSQ(I)					
Mean	41.51	25.81	28.80	0.94	*p*>.10
SD	23.20	23.56	29.97		
SSQ(24)					
Mean	9.35	4.86	3.37	0.90	*p*>.10
SD	12.98	9.17	6.13		

* Analysis of Variance; *N* = 10 each condition
** HMD-W = Helmet Mounted Display-Wide FOV
HMD-N = Helmet Mounted Display-Narrow FOV
WSD = Wide-Screen Display

Simulator sickness differences immediately versus 24 hours later. The overall mean SSQ score when measured immediately upon exiting the VE was 32.04. The overall mean SSQ score when measured 24 hours later was 5.86. This difference of 26.18 was statistically significant ($t(29) = 6.16$, $p<.001$). This difference between immediate and later report was also statistically significant for Condition 1 separately ($t(9) = 4.63$, $p<.001$), for Condition 2 separately ($t(9) = 3.01$, $p<.01$), and for Condition 3 separately ($t(9) = 3.03$, $p<.01$). Thus, there were consistent reports of less simulator sickness after the passage of time away from the virtual environment.

Correlations Between Presence and Knowlege of Hanchey Army Heliport

Since previous analyses have shown no significant differences among the conditions of the experiment (HMD-W, HMD-N, WSD) on measures of presence and also none on measures of

knowledge, all correlations between presence and knowledge were performed with data collapsed across all three experimental groups. Table 6 presents the results of the correlations between each of the three presence-related measures (SQ, ITQ, PQ) and all five posttest measures of knowledge of Hanchey. As shown in this table, there were no statistically significant correlations between scores on any of the three presence-related measures and scores on any of the five knowledge measures. In other words, there was no statistical relationship found between the reported predisposition to presence and scores on the spatial learning task. Also, there was no statistical relationship found between reported presence in the VE and the measured ability to perform the spatial learning task.

Table 6

Results of the Correlations Between the Three Presence-Related Measures and Performance on the Five Posttest Measures of Knowledge of the Hanchey Army Heliport

Test	SQ*	ITQ*	PQ*
PT Part 1 Q	$r = -.02$ $p>.10$	$r = -.17$ $p>.10$	$r = .01$ $p>.10$
PT Part 1 OP	$r = -.02$ $p>.10$	$r = -.04$ $p>.10$	$r = .03$ $p>.10$
PT Part 2 Q	$r = .06$ $p>.10$	$r = -.02$ $p>.10$	$r = .03$ $p>.10$
Nav PT (time)	$r = .11$ $p>.10$	$r = .19$ $p>.10$	$r = -.17$ $p>.10$
Nav PT (errors)	$r = -.09$ $p>.10$	$r = -.06$ $p>.10$	$r = -.20$ $p>.10$

* Pearson Product Moment Correlation; $df = 28$

SQ = Susceptibility Questionnaire

ITQ = Immersive Tendencies Questionnaire

PQ = Presence Questionnaire

Correlations Between Simulator Sickness and Knowledge of Hanchey Army Heliport

Since previous analyses have shown no significant differences among the conditions of the experiment on measures of simulator sickness and also none on measures of knowledge, all correlations between simulator sickness and knowledge were performed with data collapsed across all three experimental groups. Correlations were performed between reported simulator sickness measured immediately after exit from the VE (SSQ(I)) and posttest knowledge scores. Correlations were also performed between the simulator sickness scores reported 24 hours later (SSQ(24)) and posttest knowledge scores.

The results of these analyses are presented in Table 7. There were no statistically significant correlations between immediately reported sickness and posttest knowledge. However, as shown in Table 7, there were three negative correlations which approached significance with probabilities between five and ten percent. These involved the three paper-and-pencil posttests of knowledge (Part 1 Questionnaire, Part 1 Object Placement Test, Part 2 Questionnaire). In addition, there was a statistically significant negative correlation between performance on the Part 1 Object Placement Test and simulator sickness reported 24 hours later (r = -.36, df = 28, p<.025). These results when taken together suggest that there was a tendency for the participants who reported more simulator sickness to perform less well on the tests of spatial knowledge.

Table 7

Results of the Correlations Between Both Administrations of the Simulator Sickness Questionnaire and Performance on the Five Posttest Measures of Knowledge of the Hanchey Army Heliport

Test	SSQ(I)*	SSQ(24)*
PT Part 1 Q	*r* = -.29 .05<*p*<.10	*r* = -.21 *p*>.10
PT Part 1 OP	*r* = -.29 .05<*p*<.10	*r* = -.36 *p*<.025
PT Part 2 Q	*r* = -.28 .05<*p*<.10	*r* = -.22 *p*>.10
Nav PT (time)	*r* = -.05 *p*>.10	*r* = .21 *p*>.10
Nav PT (errors)	*r* = .10 *p*>.10	*r* = .15 *p*>.10

* Pearson Product Moment Correlation; *df* = 28
SSQ(I) = Simulator Sickness Questionnaire: Immediate
SSQ(24) = Simulator Sickness Questionnaire: 24 Hours Later

Correlations Between Presence and Simulator Sickness

All correlations were performed with data collapsed across the three conditions of the experiment. There was a statistically significant inverse relationship between scores on the Presence Questionnaire and scores on the immediately administered Simulator Sickness Questionnaire ($r = -.39$, $df = 28$, $p < .025$). In addition, there was a similar statistically significant inverse relationship between scores on the PQ and scores on the later administration of the SSQ ($r = -.33$, $df = 28$, $p < .05$). In other words, participants who reported greater levels of presence in the VE also tended to report less simulator sickness. For an illustration of the relative size of this relationship see Table 8. Of the 30 total participants, those 15 who reported the highest level of presence also reported half the level of simulator sickness, on average.

Table 8

Mean Score on the Simulator Sickness Questionnaires for the 15 Participants with the Highest Scores on the Presence Questionnaire and for the 15 Participants with the Lowest Scores on the Presence Questionnaire

Ad Hoc Group	Mean SSQ(I)*	Mean SSQ(24)*
15 Highest PQ	22.19	3.74
15 Lowest PQ	41.89	7.98

* SSQ(I) = Simulator Sickness Questionnaire: Immediate
SSQ(24) = Simulator Sickness Questionnaire: 24 Hours Later

Discussion

Spatial Learning

Learning: pretest to posttest. All participants were selected on the basis of never having visited the Hanchey Army Heliport. They all signed an affidavit to that effect. The results of the Pretest Questionnaire confirmed that the participants were naive as to the information present at HAH. As shown in Table 3, participants scored just above zero (six percent correct) on the pretest of knowledge of Hanchey. Also as shown in Table 3, there were no differences between participants in the three different visual display conditions at pretest.

This situation had changed substantially after exploration of the virtual Hanchey Army Heliport. As shown in Table 3, performance on the Posttest Part 1 Questionnaire--an instrument indentical to the Pretest Questionnaire--was significantly better than that at pretest. This was true both for data summed over all display conditions and for data from conditions analyzed separately. The overall Posttest Part 1 Questionnaire score improved to 82 percent correct. The overall Posttest Part 1 Object Placement Test score was 79 percent correct. The overall Posttest Part 2 Questionnaire score was 87 percent correct. Also, all participants successfully performed the Navigation Posttest with a mean overall error rate of fewer than one wrong turn per participant (see Table 3). Clearly, participants were

able to gain important information from exploration of the virtual Hanchey environment and to transfer this information to the actual, physical heliport. These results are consistent with earlier ARI research showing that both interior spatial knowlege (Witmer et al., 1995) and exterior spatial knowledge (Johnson & Wightman, 1995) can be trained using VE technology.

The effect of the visual display conditions on learning. As shown in Table 3 there was no effect whatsoever of the visual display conditions on learning. There were no display effects on any of the five posttest measures--whether questionnaires, object placement, navigation time, or navigation errors. Interestingly, the posttest measures varied from paper-and-pencil knowledge tests administered both at ARI and at the heliport, to whole body, walking navigation times and errors administered at the heliport. All three visual displays--though different in FOV, head tracking, and resolution--were equally able to transmit the information that the participants needed to learn the physical configuration, landmarks, routes, and aircraft traffic patterns of the Hanchey Army Heliport.

These empirical results argue against a widespread, but untested, belief held by proponents of virtual environment technology who publish in the popular scientific press. This belief is that a helmet-mounted display with wide FOV and high resolution is best for the learning of specifically visual-spatial information (e.g., Akstakalnis & Blatner, 1992; Pimentel & Teixeira, 1993; Rheingold, 1991). Clearly, there was no evidence in this experiment that a wide-FOV, high-resolution, head-tracked, helmet-mounted display was superior to other display types for the learning of visual-spatial information. All three visual display conditions met the requirements for a virtual environment interface as set forth by Regian et al. (1992). That is, the Hanchey synthetic environment preserved the visual-spatial characteristics of the actual Hanchey Army Heliport. Further, all three visual display conditions preserved the linkage between motor actions and resultant effects that exist in the real world. As a result, all three display conditions were equally able to provide the spatial information necessary for participants to develop a valid spatial representation of the HAH.

Presence

The effect of the visual display conditions on reported presence. Prior to exploration of the virtual environment all participants were administered both the Susceptibility Questionnaire and the Immersive Tendencies Questionnaire. Both instruments were designed to predict those individuals most likely to experience presence in the VE based on interests, experiences, and habits. Since participants were randomly assigned to conditions of the experiment, there was no reason to expect that the experimental groups would differ prior to their exploration of the VE. As shown in Table 4, there were, in fact, no differences among the groups in their scores on the SQ or the ITQ.

Presence in the VE is the experience of being physically present within the synthetic environment. It is a feeling which the Presence Questionnaire was designed to measure based on self report upon exit from the VE. Among the conditions said to produce a sense of presence is being immersed in a virtual world via a high-resolution, wide-FOV, head-tracked, helmet-mounted display. Condition 1 was designed to be such an environment. Participants explored a large, detailed, active, synthetic heliport with a high-resolution, wide-FOV, head-tracked, helmet-mounted display. Condition 2 was identical except that the FOV was severely restricted. Participants in Condition 2 were essentially viewing the synthetic environment through a small, rectangular, movable porthole in the side of a surrounding black wall. Condition 3 employed a stationary, wide-screen, lower-resolution display. This was a conventional display common to aircraft simulators and as such made for an interesting baseline comparison. It was not an "immersive" display. In Conditions 1 and 2 participants were totally immersed in the synthetic visual environment. Regardless of FOV, wherever the participants looked they were still within the VE. This was definitely not true for the participants in Condition 3. These participants were clearly aware that they were sitting in a blanket-covered helicopter cockpit while looking at a large display screen which was itself located in a large and varied simulator bay. By looking far enough up, down, left, or right participants could shift their perspective entirely out of the virtual world. Condition 1 should have produced greater ratings of presence than either Condition 2 or Condition 3. Yet, as shown in Table 4, there were no differences in measured presence.

This empirical result is contrary to the widely held, but untested, speculation of many (e.g., Aukstakalnis & Blatner, 1992; Pimentel & Teixeira, 1993; Psotka & Davison, 1993; Psotka, Davison, & Lewis, 1993; Rheingold, 1991; Sheridan, 1992; Witmer & Singer, 1994). How could this have happened? Given these substantial differences in display characteristics how is it that no measureable differences in presence were reported? Two related explanations present themselves. First, perhaps the Presence Questionnaire, in its current version, is not sufficiently sensitive to be used for between groups comparisons. The developers of the PQ state repeatedly that the instrument is a research product in progress and that it is continuing to undergo modifications in content and scoring (Singer & Witmer, 1995; Witmer & Singer, 1994). Second, and related, perhaps the experience of presence is still largely unmeasureable because it is not yet clearly understood. Virtual reality pioneers "know it when they see it" but otherwise have a difficult time explaining the concept of presence. The subjective experience of presence within a virtual environment is obviously not an easy psychological state to measure. The difficulties and vagueries of measuring presence have been noted before by some of these same pioneers (e.g., Held & Durlach, 1992; Sheridan, 1992; Witmer & Singer, 1994). At any rate, further research is needed. Given the importance of the concept of presence to the field of virtual reality and virtual environments, further research will most assuredly be forthcoming.

Individual differences in predisposition to experience presence. Both the Susceptibility Questionnaire and the Immersive Tendencies Questionnaire were designed to measure individual differences in the predisposition to experience presence in the VE. As expected, the two instruments intercorrelated significantly, affirming that they both measure a common factor or factors. Whether this common factor is the predisposition to experience presence, however, is still open to question.

With data summed over all three conditions of visual display--the "appropriate analysis" since there were no effects of visual display on anything--there was no significant correlation between performance on either the SQ or the ITQ and the experience of presence as measured by the PQ. In other words, overall there was no statistical relationship between the instruments which attempt to predict presence and the measure of

presence itself. These results can be interpreted as casting suspicion on either the predictive instruments or the criterion instrument or both. Witmer et al. (1995) were also unable to obtain a significant correlation between ITQ and PQ in their recent spatial learning experiment.

Interestingly, when the data were analyzed separately by condition, it was discovered that for Condition 3 alone SQ correlated significantly with PQ. Also, for Condition 3 alone, ITQ correlated significantly with PQ. Assuming that these were not merely Type I errors but valid relationships, how can they be explained? Remember that Condition 3 employed the stationary, wide-screen, visual display--not a helmet-mounted display. Remember also that Condition 3 was considered a priori to be nonimmersive. It follows, then, that in the absence of an immersive display those participants most strongly predisposed to experience presence did report more presence than those participants less strongly predisposed. In other words, in the absence of an immersive display, the experience of presence was driven by predisposing factors (individual differences). To the extent that both this reasoning and these results are valid, to that extent there is evidence here in support of the validity of all three presence-related measuring instruments (SQ, ITQ, PQ). Note, Psotka and Davison (1993) reported a significant, positive correlation between SQ and their measure of presence called the Total Immersion Scale (not used in this experiment). In any case, future research is needed to continue the development and/or validation of measures of presence and predisposition to presence.

Simulator Sickness

The effect of the visual display conditions on reported symptoms of simulator sickness. All but one of the 30 participants reported that they were physically fit, sober, unmedicated, and rested prior to their exploration of the virtual environment. The Simulator Sickness Questionnaire was completed both immediately upon exit from the VE and 24 hours later. As shown in Table 5, there was no significant effect of the visual display conditions upon reported sickness--either immediately or later.

It was somewhat surprising that a significant effect of visual display upon simulator sickness did not emerge in this experiment. It has been widely reported for stationary, cathode

ray tube and dome displays used in aviation simulators that increasing FOV produces greater simulator sickness (e.g., Kennedy, Berbaum, & Lilienthal, 1992; Kennedy, Berbaum, Smith, & Hettinger, 1992; Kolasinski, 1995; Pausch, Crea, & Conway, 1992). Why not in this experiment?

First, there can be no serious doubt of the validity of the SSQ which has undergone a long, technically-exacting development and validation process (Kennedy, Lane, Berbaum, & Lilienthal, 1993). So, questioning the validity of the measuring instrument does not appear to be a fruitful approach. Second, it is possible that empirical effects found using stationary visual displays are not the same as those employing helmet-mounted displays. Although such a phenomenon has by no means been established scientifically, rumors to the effect that HMDs are inordinately nauseogenic have recently been spreading throughout VE research laboratories (e.g., Biocca, 1992; DMSO, 1994). The term virtual reality sickness has been coined, presumably because someone believes it to be different from simulator sickness (DMSO, 1994).

Third, and most likely, it is probable that the effect of FOV on simulator sickness is simply a small effect in comparison to the variability in susceptibility to simulator sickness which exists in the human population. If the FOV effect is real but small, all that is required for validation is a sample size substantially larger than the current experiment's ten per group. Note that the mean differences between Conditions 1 and 2 in this experiment were in the hypothesized direction. There is large individual variability in susceptibility to simulator sickness (Kennedy, Berbaum, & Lilienthal, 1992). For this reason, Kennedy, Berbaum, and Lilienthal recommend greater than 50 participants per treatment condition for experimental work. These authors, for example, report an effect of FOV on simulator sickness based upon a database of greater than 7000 human exposures (Kennedy, Berbaum, & Lilienthal, 1992). Of course, adding $\underline{N}$ to a simulator-based experiment such as the current one is very resource intensive.

Simulator sickness immediately after exposure and later. As shown in Table 5, the symptoms of simulator sickness reported were significantly and substantially greater immediately after exposure to the VE than 24 hours later. The fact that the symptoms of simulator sickness are attenuated after a period of time away from the simulator has been reported before based on

research in aviation simulators (e.g., Biocca, 1992; Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992; Kolasinski, 1995; Pausch, Crea, & Conway, 1992; Wright, 1995).

Known residual aftereffects of simulator exposure include locomotor ataxia (i.e., disturbances of gait, difficulty in coordinating voluntary movements), interference with higher-order motor control, physiological discomfort, and visual aftereffects including flashbacks (e.g., Kennedy, Berbaum, & Lilienthal, 1992; Kennedy, Berbaum, Smith, & Hettinger, 1992). These aftereffects have been reported to last hours, days, and--rarely--a week or more (e.g., Wright, 1995). Thus, it is widely reported that the aftereffects of simulator exposure have the potential to create safety hazards in the operation of heavy equipment, airplanes, automobiles, and around the home (e.g., Kennedy, Fowlkes, & Lilienthal, 1993; Kennedy, Lane, Lilienthal, Berbaum, & Hettinger, 1992; Pausch, Crea, & Conway, 1992; Wright, 1995). As a result the military services regulate how soon after a simulator session aviators are allowed to pilot aircraft (Kennedy, Berbaum, & Lilienthal, 1992; Kennedy, Berbaum, Smith, & Hettinger, 1992).

The Relationship Between Presence and Knowledge of the Hanchey Army Heliport

As shown in Table 6, individual differences reported in the three presence-related questionnaires (SQ, ITQ, PQ) did not correlate significantly with scores on any of the five posttest measures of knowledge. Participants who reported a greater tendency to become immersed on the Susceptibility Questionnaire and the Immersive Tendencies Questionnaire were neither more nor less likely to score higher on posttest measures of spatial knowledge. These results are not consistent with those of Witmer et al. (1995) who reported a significant correlation between ITQ scores and four measures of configuration knowledge.

Participants who reported more presence within the virtual environment on the Presence Questionnaire were also neither more nor less likely to score higher on posttest measures of spatial knowledge. These results, however, are consistent with those of Witmer et al. (1995) who also failed to find an hypothesized significant relationship between PQ scores and measures of spatial knowledge.

The Relationship Between Simulator Sickness and Knowledge of the Hanchey Army Heliport

As shown in Table 7, there was an inverse relationship between reported simulator sickness and measured knowledge of the Hanchey Heliport. Participants who reported the higher levels of sickness tended to perform less well on tests of knowledge. This makes sense. It is reasonable to conclude that participants experiencing symptoms of simulator sickness are busy attending to internal cues (their feelings) and are less attentive to external cues (the spatial information in the VE). It is no surprise that participants experiencing discomfort learn less well than healthy participants. It is just this negative correlation which has caused some to question the potential of VE technology for widespread use (e.g., Biocca, 1992). Clearly the issue of simulator sickness is one which will have to be dealt with in some fashion if the military services intend to employ simulators and simulation networks for widespread individual and collective training (e.g., DMSO, 1994).

The Relationship Between Presence and Simulator Sickness

There was a consistent and significant inverse relationship between presence and simulator sickness. Again, this makes sense. Participants attending to cues provided by their sickness are not able to attend as strongly to other aspects of the virtual environment. Participants experiencing discomfort are less likely to be concentrating on their experience of immersion in the VE. In other words, being sick detracts from the immersive experience of "being there" or presence. This situation is common in everyday life. Who has not had their enjoyment of and integration into a special event ruined by sickness, physical pain, or even just worries? This negative correlation between presence and simulator sickness was also found by Witmer and colleagues (Witmer et al., 1995; Witmer & Singer, 1994).

Conclusions

Soldiers used virtual environment technology to perform self-guided exploration of a synthetic representation of a Fort Rucker heliport that they had never previously visited. A pretest showed that the soldiers were, in fact, naive with regard to this location. A series of posttests demonstrated that the

soldiers were able to learn important spatial features of the heliport using the virtual representation. When transferred to the actual heliport, the soldiers were able to navigate from memory to unseen locations with near zero errors on their first visit. This experiment provided further evidence that spatial information can be transmitted using virtual environment technology as the instructional medium and that this information will transfer to the real world.

Soldiers in this experiment were randomly assigned to three visual display conditions for viewing the synthetic environment. Condition 1 was a wide-FOV, high-resolution, helmet-mounted display. Condition 2 was a narrow-FOV, high-resolution, helmet-mounted display. Condition 3 was a conventional, stationary, lower-resolution, wide-screen display. The type of visual display used by soldiers to view the virtual environment made no difference in the amount learned, the reported experience of presence, or the severity of simulator sickness.

There was no relationship between reported presence and amount learned in the virtual environment. The extent to which soldiers felt themselves physically present within the computer-generated virtual world neither helped nor hindered their learning about the heliport.

There was an inverse relationship between simulator sickness and amount learned in the synthetic environment. Soldiers who reported greater levels of discomfort tended to learn less about the heliport than their peers who experienced less simulator sickness.

The amount of simulator sickness reported immediately upon exit from the synthetic environment was substantially reduced after a period of 24 hours spent away from the simulator.

There was an inverse relationship between simulator sickness and reported presence in the synthetic environment. Soldiers reporting greater levels of simulator sickness also reported less presence.

REFERENCES

Alluisi, E. A. (1991). The development of a technology for collective training: SIMNET, a case history. Human Factors, 33(3), 343-362.

ARI (1995). STRATA: What has been accomplished. ARI Newsletter, 5(2), 7-12.

Aukstakalnis, S., & Blatner, D. (1992). Silicon mirage: The art and science of virtual reality. Berkeley: Peachpit Press.

Bell, H. H., Mastaglio, T. W., & Moses, F. (1993). Using distributed interactive simulations for joint service training. Military Simulation & Training, 5, 28-30.

Biocca, F. (1992). Will simulation sickness slow down the diffusion of virtual environment technology? Presence, 1(3), 334-343.

Bruning, J. L., & Kintz, B. L. (1968). Computational handbook of statistics. Glenview: Scott, Foresman.

DMSO (1994). Virtual Reality (VR) Modeling and Simulation Conference Summary. Washington, DC: Defense Modeling and Simulation Office.

Drabczuk, J. S., & Tarr, R. W. (1993). Distributed Interactive Simulation (DIS): A new way for the Army. Army Aviation, 42(7), 32-38.

DRG (1995). Simulated battle conditions reduces Army exercise costs. Simulation Newsletter, 1(2), 3.

Ellis, S. R. (1991). Nature and origins of virtual environments: A bibliographical essay. Computing Systems in Engineering, 2(4), 321-347.

Essex (no date given). Pre-hop physiological status information. Orlando: Essex Corp.

Gaito, J. (1980). Measurement scales and statistics: Resurgence of an old misconception. Psychological Bulletin, 87(3), 564-567.

Gilkey, R. H., & Weisenberger, J. M. (1995). The sense of presence for the suddenly deafened adult: Implications for virtual environments. Presence, 4(4), 357-363.

Goldiez, B. (1995). DIS technology. Proceedings of the Eleventh Workshop on the Standards for the Interoperability of Distributed Simulations March 1995. Orlando: Author.

Hays, R. T., & Singer, M. J. (1989). Simulation fidelity in training system design. New York: Springer-Verlag.

Held, R. M., & Durlach, N. I. (1992). Telepresence. Presence, 1(1), 109-112.

Johnson, D. M., & Wightman, D. C. (1995). Using virtual environments for terrain familiarization: Validation (ARI Research Report 1686). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Kennedy, R. S., Berbaum, K. S., & Lilienthal, M. G. (1992). Human operator discomfort in virtual reality systems: Simulator sickness--causes and cures. In S. Kumar (Ed.), Advances in industrial ergonomics and safety IV (pp. 1227-1234). New York: Taylor & Francis.

Kennedy, R. S., Berbaum, K. S., Smith, M. G., & Hettinger, L. J. (1992). Differences in simulator sickness symptom profiles in different simulators: Application of a "field experiment" method.. Presented at the IMAGE VI Conference Scottsdale, Arizona 14-17 July, 1992.

Kennedy, R. S., Fowlkes, J. E., & Lilienthal, M. G. (1993). Postural and performance changes following exposure to flight simulators. Aviation, Space, and Environmental Medicine, 64, 912-920.

Kennedy, R. S., Lane, N. E., Berbaum, K. S., & Lilienthal, M. G. (1993). Simulator Sickness Questionnaire: An enhanced method for quantifying simulator sickness. The International Journal of Aviation Psychology, 3(3), 203-220.

Kennedy, R. S., Lane, N. E., Lilienthal, M. G., Berbaum, K. S., & Hettinger, L. J. (1992). Profile analysis of simulator sickness symptoms: Application to virtual environment systems. Presence, 1(3), 295-301.

Keppel, G. (1973). Design and analysis: A researcher's handbook. Englewood Cliffs: Prentice-Hall.

Kolasinski, E. M. (1995). Simulator sickness in virtual environments (ARI Technical Report 1027). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A295 861)

Krueger, M. W. (1991). Artificial reality II. New York: Addison-Wesley.

Kurts, D., & Gainer, C. A. (1991). The use of a dedicated testbed to evaluate simulator training effectiveness. In Piloted Simulation Effectiveness Conference, AGARD Conference Proceedings No. 513. Brussels, Belgium: North Atlantic Treaty Organization, 11-1 to 11-9.

Landry, L. A. (1994). The Aviation combined Arms Tactical Trainer. U.S. Army Aviation Digest, 1-94-2, 15-17.

Mogal, J. (1993). Virtual reality--a primer. IRIS Universe, 25, 22-24.

Moshell, M., Blau, B., & Dunn-Roberts, R. (1993). Virtual environments for military training: SIMNET, Ender's Game, and beyond. Virtual Reality World, 1(2), v-ad.

Mowafy, L., & Congdon, T. (1994). Air combat surveillance in a virtual world training system. Presented at the IMAGE VII Conference Tucson, Arizona.

Mowafy, L., & Miller, L. (1993). Visualizing spatial relationships: Training fighter pilots in a virtual environment debrief interface (AL/HR-TR-1993-0148). Mesa, AZ: Aircrew Training Research Division, Human Resources Directorate, Armstrong Laboratory.

Pausch, R. (1993). Three views of virtual reality: An overview. Computer, 26(6), 79-80.

Pausch, R., Crea, T., & Conway, M. (1992). A literature survey for virtual environments: Military flight simulator visual systems and simulator sickness. Presence, 1(3), 344-363.

Pimentel, K., & Teixeira, K. (1993). Virtual reality: Through the new looking glass. New York: McGraw-Hill.

Psotka, J. (1994). Personal communication--how to score the Susceptibility Questionnaire.

Psotka, J., & Davison, S. A. (1993). Cognitive factors associated with immersion in virtual environments. In Proceedings of the 1993 Conference on Intelligent Computer-Aided Training and Virtual Environment Technology, May 1993. Houston: Author.

Psotka, J., Davison, S. A., & Lewis, S. A. (1993). Exploring immersion in virtual space. Virtual Reality Systems, 1(2), 70-92.

Regian, J. W., Shebilske, W. L., & Monk, J. M. (1992). Virtual reality: An instructional medium for visual-spatial tasks. Journal of Communication, 42(4), 136-149.

Rheingold, H. (1991). Virtual reality. New York: Simon & Schuster.

Roos, J. G. (1995). Is it for real? Armed Forces Journal International, January, 24-26.

Selix, G. (1993). Evolution of a training program: The effects of simulation on the MH-53J PAVE LOW combat crew qualification course. Proceedings of the 15th Interservice/Industry Training Systems and Education Conference November 29- December 2, 1993. 422-431. Orlando: I/ITSEC.

Sheridan, T. B. (1992). Musings on telepresence and virtual presence. Presence, 1(1), 120-125.

Singer, M. J., & Witmer, B. G. (1995). Presence measures for virtual environments: Background & scoring instructions (Unpublished ARI Letter Report).

Singley, G. T. (1993). Distributed Interactive Simulation--a preview. Army Research, Development and Acquisition Bulletin, PB 70-93-2, 35-39.

Sottilare, R. (1995). Synthetic theatre of war--Europe. Army Research, Development and Acquisition Bulletin, PB 70-95-2, 18-20.

Stewart, J. E. (1994). Using the backward transfer paradigm to validate the AH-64 Simulator Training Research Advanced Testbed for Aviation (ARI Research Report 1666). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A285 758)

Stewart, J. E., Wightman, D. C., & Gainer, C. A. (1993). Research prospectus for the Simulator Training Research Advanced Testbed for Aviation (ARI Technical Report 980). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A268 165)

U.S. Army Research Office (1992). Workshop report: Virtual reality/synthetic environments in Army training. Durham, NC: Author.

Vaden, D. W. (1993). Vision for the next decade. Army Research, Development and Acquisition Bulletin, PB 70-93-3, 1-3.

Wenzel, E. M. (1992). Localization in virtual acoustic displays. Presence, 1(1), 80-107.

Wiener, E. L., & Nagel, D. C. (1988). Human factors in aviation. San Diego: Academic.

Witmer, B. G., Bailey, J. H., & Knerr, B. W. (1995). Training dismounted soldiers in virtual environments: Route learning and transfer (ARI Technical Report 1022). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

Witmer, B. G., & Singer, M. J. (1994). Measuring presence in virtual environments (ARI Technical Report 1014). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A286 183)

Wright, R. H. (1995). Helicopter simulator sickness: A state-of-the-art review of its incidence, causes, and treatment (ARI Research Report 1680). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (AD A297 285)

Yuhas, J. S. (1993). Distributed Interactive Simulation. Army Research, Development & Acquisition Bulletin, PB 70-93-3, 4-6.

APPENDIX

1. Demographic Information Form
2. Pretest Questionnaire
3. Posttest Part 1 Questionnaire
4. Posttest Part 1 Object Placement Test
5. Posttest Part 2 Questionnaire
6. Hanchey Army Heliport Walking Navigation Test

Date ___________ Condition ________ Participant #________

Demographic Information Form

All information you provide will be used for research purposes only. Your anonymity is assured.

1. Name: ____
   Last First Middle

2. Social Security No: ___ ___ ___ - ___ ___ - ___ ___ ___ ___

3. What is your age? ____________ Years

4. What is your current rank? _________________________

5. To which unit are you assigned? __________________________

6. Daytime Telephone Number(s): _______________________________

7. Are you an aviator? ___________________________

8. Have you ever visited Hanchey Army Heliport? _______________

____
Your Signature

Date ____________ Condition ________ Participant #________

Pretest Questionnaire

Please answer all questions. Circle the correct answer where appropriate. Guessing is permitted. If you do not know what the answer is and do not wish to guess, write "DK" for don't know.

1. Which helicopter type (types) is (are) based on the West ramp at Hanchey Army Heliport?

2. Which helicopter type (types) is (are) based on the East ramp at Hanchey Army Heliport?

3. In which compass orientation are the helicopters parked on the West ramp at Hanchey? North-South orientation or East-West orientation?

4. In which compass orientation are the helicopters parked on the East ramp at Hanchey? North-South orientation or East-West orientation?

5. How many helipads are located on the West ramp of Hanchey?

6. How are these helipads identified or designated? (That is, list the identification or designation of each of these helipads.)

7. Which traffic pattern is at a higher altitude? West Hanchey traffic pattern or East Hanchey traffic pattern?

8. How many windsocks are located at Hanchey?

9. Where is (are) the windsock(s) located relative to the control tower? Use compass direction (i.e., North, South, East, West) to locate each windsock.

10. Where is the beacon tower located relative to the control tower? North, South, East, or West?

11. Where is the fire station located relative to the control tower? North, South, East, or West?

12. Where are the fuel tanks located relative to the control tower? North, South, East, or West?

13. How many fuel tanks are there?

14. What is the field elevation of Hanchey in feet?

Date ____________ Condition ________ Participant #________

Posttest Part 1 Questionnaire

Please answer all questions. Circle the correct answer where appropriate. Guessing is permitted. If you do not know what the answer is and do not wish to guess, write "DK" for don't know.

1. Which helicopter type (types) is (are) based on the West ramp at Hanchey Army Heliport?

2. Which helicopter type (types) is (are) based on the East ramp at Hanchey Army Heliport?

3. In which compass orientation are the helicopters parked on the West ramp at Hanchey? North-South orientation or East-West orientation?

4. In which compass orientation are the helicopters parked on the East ramp at Hanchey? North-South orientation or East-West orientation?

5. How many helipads are located on the West ramp of Hanchey?

6. How are these helipads identified or designated? (That is, list the identification or designation of each of these helipads.)

7. Which traffic pattern is at a higher altitude? West Hanchey traffic pattern or East Hanchey traffic pattern?

8. How many windsocks are located at Hanchey?

9. Where is (are) the windsock(s) located relative to the control tower? Use compass direction (i.e., North, South, East, West) to locate each windsock.

10. Where is the beacon tower located relative to the control tower? North, South, East, or West?

11. Where is the fire station located relative to the control tower? North, South, East, or West?

12. Where are the fuel tanks located relative to the control tower? North, South, East, or West?

13. How many fuel tanks are there?

14. What is the field elevation of Hanchey in feet?

Date ____________ Condition ________ Participant #________

Posttest Part 1 Object Placement Test

Use the generalized diagram of Hanchey Army Heliport provided. Place the following objects on the diagram in their correct locations. Guessing is permitted. If you do not know the answer and do not wish to guess, leave the question blank and go on. Please read through all questions first before answering any.

1. Put a "WS" wherever a windsock is located.

2. Put a "CT" where the control tower is located.

3. Put a "BT" where the beacon tower is located.

4. Label each helipad with its appropriate identifying designation.

5. Put an "FT" where the fuel tanks are located.

6. Put a "CH" where Cobra Hall is located.

7. Put a "WCH" where the Windjammers Chinook Hall is located.

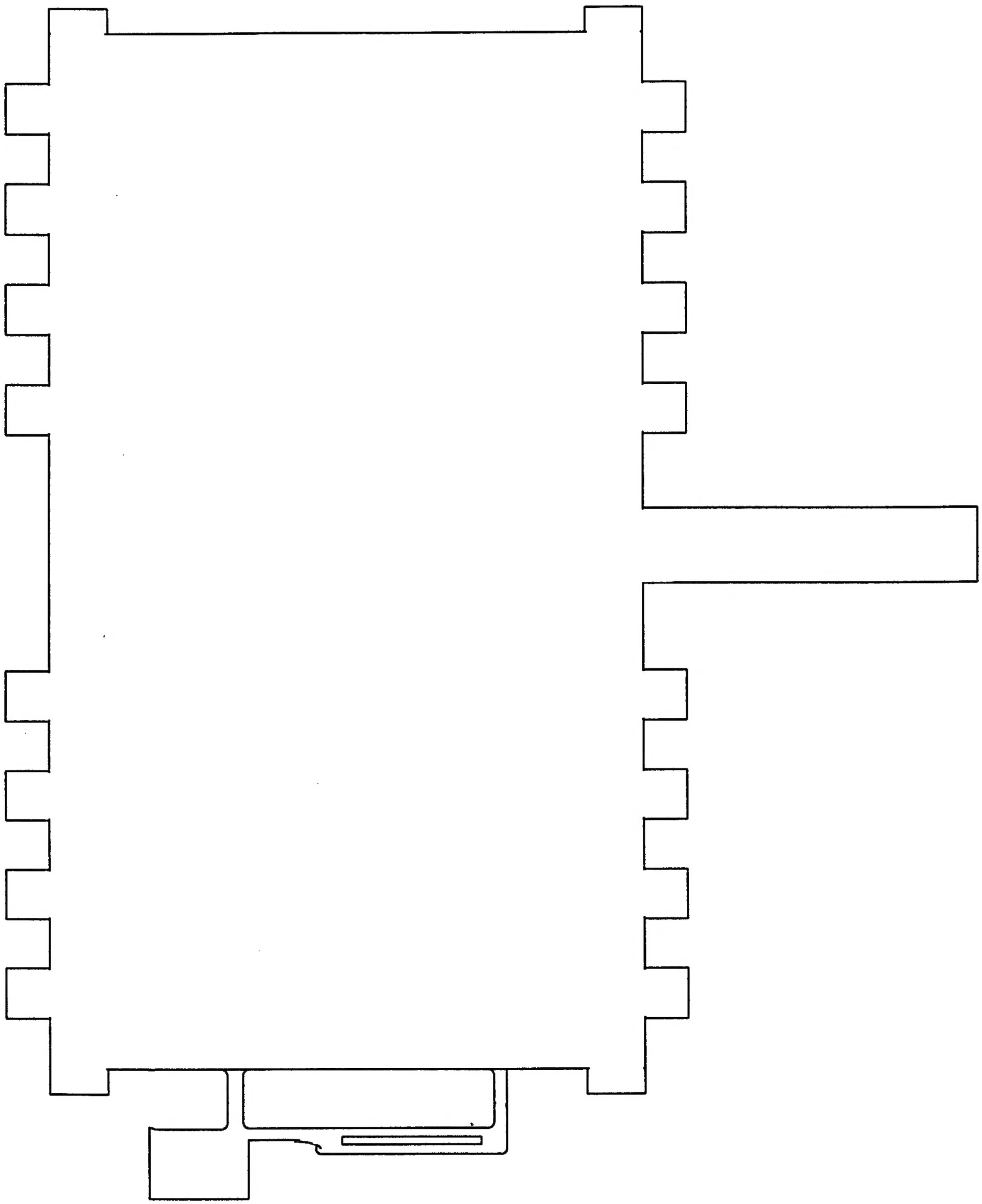
8. Put an "HWC" where the Warrior Country hangar is located.

9. Put an "H" where each of the other two hangars are located.

10. Put an "FE" where each of the two field elevation signs are located.

11. Put an "FS" where the fire station is located.

12. Put the appropriate helicopter types, by name or alphanumeric designation, on the appropriate sides of the ramp.



Date ____________ Condition ________ Participant #________

Posttest Part 2 Questionnaire

I am going to remove your goggles. Hold your head and eyes steady and pointed forward. Do not turn your head to the left or the right. Do not move from this spot. I am going to ask you some questions. Please answer all questions. Guessing is permitted. If you do not know an answer and do not wish to guess, say "don't know."

a. Do you see the "Warrior Country" logo? Yes No

1. Where is the control tower located relative to your position? To your front, back, left, or right? DK

2. Where is the fire station located relative to your position? To your front, back, left, or right? DK

3. Which helicopter type or types are parked to your left?
AH-64 Apache AH-1 Cobra CH-47 Chinook OH-58 Kiowa
UH-60 Blackhawk UH-1 Huey TH-67 Creek RAH-66 Comanche
DK

4. Which helicopter type or types are parked to your right?
AH-64 Apache AH-1 Cobra CH-47 Chinook OH-58 Kiowa
UH-60 Blackhawk UH-1 Huey TH-67 Creek RAH-66 Comanche
DK

5. Where is Cobra Hall relative to your position? To your front, back, left, or right? DK

6. Where is the beacon tower relative to your position? To your front, back, left, or right? DK

7. Where is the antenna pole relative to your position? To your front, back, left, or right? DK

8. Where are the fuel tanks relative to your position? To your front, back, left, or right? DK

9. Where is the water tank relative to your position? To your front, back, left, or right? DK

10. Where is the nearest "field elevation" sign to your position? To your front, back, left, or right? DK

11. Where is taxi lane Delta relative to your position? To your front, back, left, or right? DK

12. Where is taxi lane Echo relative to your position? To your front, back, left, or right? DK

13. Which aircraft traffic pattern is at a higher altitude, the traffic pattern to your left or the traffic pattern to your right? Left Right DK

14. Relative to your position, is there a windsock:

To your front?	Yes	No	DK
To your back?	Yes	No	DK
To your left?	Yes	No	DK
To your right?	Yes	No	DK

15. Where is Windjammers Chinook Hall relative to your position? To your front, back, left, or right? DK

16. Where are the two silver natural gas tanks relative to your position? To your front, back, left, or right? DK

17. Where is the satellite receiver dish relative to your position? To your front, back, left, or right? DK

Date ____________ Condition ________ Participant #________

Hanchey Army Heliport Walking Navigation Test

GENERAL INSTRUCTIONS. There will be two walks. I will give you the destination and any waypoints I want you to pass. You will lead. I will follow behind you with my clipboard and stopwatch. Walk as fast as you want as long as I can keep up. If you make a wrong turn, I will say "stop." You should immediately choose another direction and continue walking. Do you understand?

PRACTICE WALK. [Starting Point: Warrior Country hangar reset position] There are two field elevation signs on this heliport. Please walk to and stand under the nearest field elevation sign. Use the shortest route without passing through any buildings. Do you understand?

Time____________________ Wrong Turns__________________

DATA WALK. [Starting Point: Under field elevation sign on Warrior Country hangar] Please walk to the two silver natural gas tanks, passing on your way first the two brown dumpsters then the other field elevation sign. Use the shortest route without passing through any buildings. Do you understand?

Time____________________ Wrong Turns__________________